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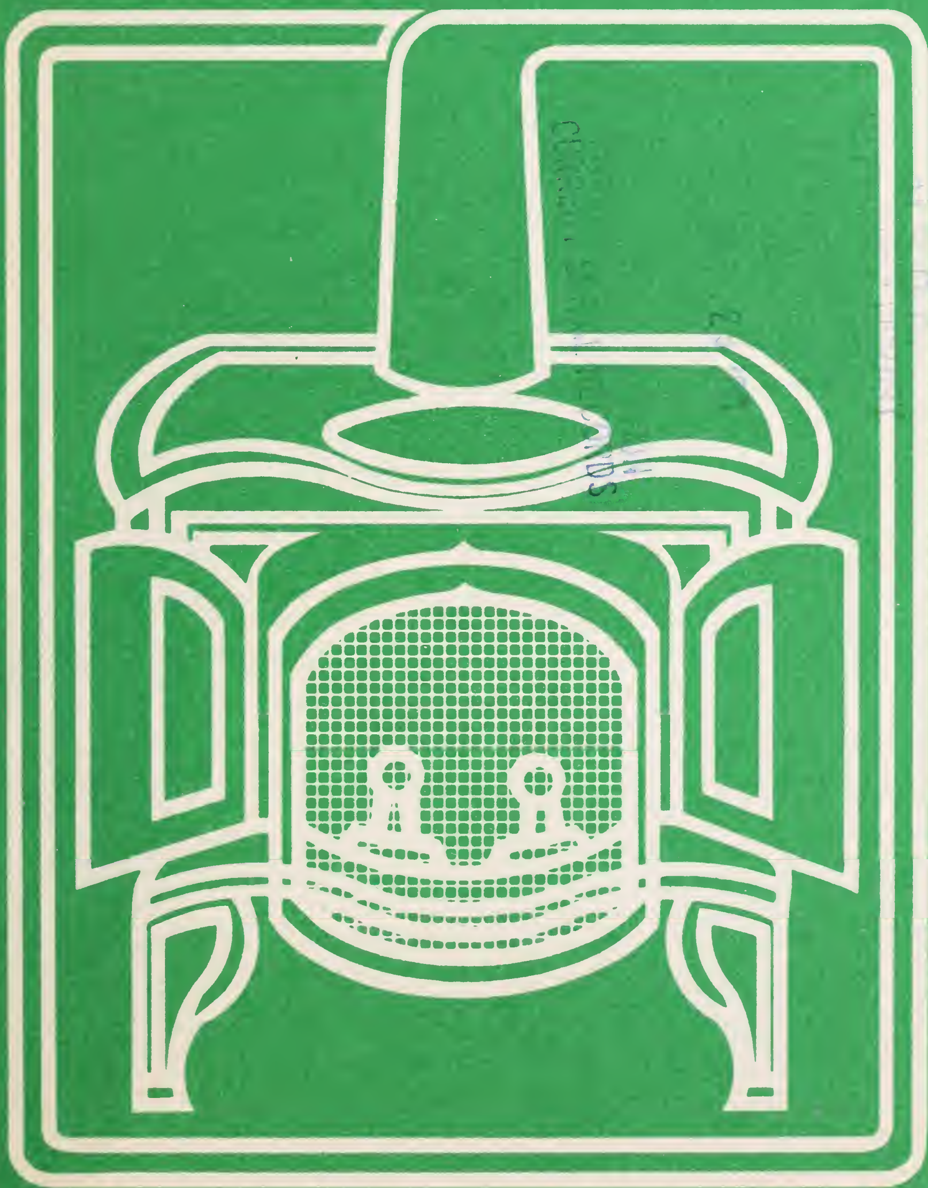
Wood and Energy In New England

A Review and Bibliography

Lynn Palmer
Robert McKusick
Mark Bailey



WOOD AND ENERGY IN NEW ENGLAND: A REVIEW AND BIBLIOGRAPHY. By Lynn Palmer, Robert McKusick, and Mark Bailey. Natural Resource Economics Division; Economics, Statistics, and Cooperatives Service; U.S. Department of Agriculture. Bibliographies and Literature of Agriculture No. 7

ABSTRACT

Because of New England's dependence on petroleum products for energy (89 percent of total energy consumed in 1976 including natural gas), its energy costs are nearly 30 percent higher than the national average. Forest land, covering almost 80 percent of New England, contains a huge volume of fuelwood that could potentially provide the equivalent of 55 million barrels of oil a year. This report reviews a number of fuelwood feasibility studies, fuelwood's role in the national and regional energy picture, wood availability and demand, energy alternatives, and environmental impact.

Key words: Wood energy, fuelwood, chemicals from wood, New England, forest land, wood residue, timber stand improvement

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PREFACE

Wood and Energy in New England: A Review and Bibliography, part of the New England Fuelwood Study sponsored by the Soil Conservation Service (SCS), was prepared by the Economics, Statistics, and Cooperatives Service, under an agreement with SCS. This report summarizes the literature review undertaken as part of the study. It lists 130 articles, reports, and books dealing with the wood energy situation, 60 of which are annotated.

The New England Fuelwood Study investigates the potential of wood as a substitute for other energy forms, the impact on forest resources of utilizing low-quality wood for firewood, and the impact on local employment opportunities.

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WOOD AND ENERGY IN NEW ENGLAND
A Review and Bibliography

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INTRODUCTION

Wood has had a minor role as a fuel during this century in the United States. Due to diminishing supplies and rising prices, however, today's modern fuels may meet the earlier fate of fuelwood and coal when they were replaced by less expensive and more convenient oil and natural gas. A majority of New England's energy requirements (89 percent) is filled by petroleum, including residential and industrial heating, the production of electricity, and transportation. The high costs and shortages of modern fuels may generate significant demand for wood energy, especially in New England which is currently more dependent on fossil-fuel energy than any region in the Nation.

This report reviews publications produced by wood-energy related research projects. It lists 130 references, nearly 60 of which are annotated. A number of central information services—CAIN, AGRICOLA, ENVIROLINE, SCISEARCH—were examined, but the Current Research Information System (CRIS) was the main system used.

This report is not limited to solid wood energy but also reviews literature regarding energy forms derived from processing solid forms of wood. Although past research assumed that wood was only economical when used for commercial energy, this report emphasizes fuelwood for residential heating use. A survey conducted by each of the New England States examines in detail residential demand for wood energy. Reports on these surveys should be available by June 1, 1980.

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*Lynn Palmer, a former intern with ESCS, prepared the first draft of this report. Dr. McKusick was formerly the Small Watershed/Resource Conservation and Development Porgram Leader with ESCS. Dr. Bailey, an agricultural economist with ESCS, prepared subsequent drafts and is the New England Fuelwood Study Project Leader.

Energy Price Differential

New England's vast wood supply could narrow the energy price differential between New England and the rest of the United States. Compared to the U.S. average price paid for electricity (2.890 cents per kWh), a New Englander pays about 45 percent more (4.188 cents per kWh) (*82*).[1] The region has no immediately usable native fossil fuels, and imported oil provides 79 percent of the region's total petroleum demand. Oil is used to generate 57 percent of the region's electricity (*82*). Because of this high dependence on petroleum, the Governors of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont have taken measures to control oil dependence by setting a target to decrease dependence by 20 percent within the next 10 years. The six Governors' Energy Policy aims to limit petroleum dependence to 65 percent of the region's total energy needs by 1985 (*82*).[2] By conserving about 97 million barrels of oil per year and increasing use of nuclear power, coal, and other types of energy as per the policy guidelines, the region hopes to meet the 20-percent decrease in oil dependence.

Fuelwood Feasibility Studies

Fuelwood feasibility and impact analysis studies usually take one of three approaches or a fourth less common approach:

1) They may ignore the energy potential of wood resources traditionally allocated to forest product industries, though they do analyze the remaining underutilized forest resources and residues for energy (*6*, *30*, *35*, *49*, *79*).
2) They may take the entire forest area approach which recommends fuller use of residues through removing suppressed, dead, and cull material only, leaving healthy, salable roundwood (*66*) (*86*) (*95*).
3) They may recommend using wood supplies mentioned in the first two approaches plus the supplies found in the differential between annual growth and removals. One study bases its recommendations on the sizable gap between annual growth figures and harvests in an attempt to narrow that gap (*114*).
4) They sometimes do not exclude any portion of the forest resource. In other words, the market will allocate wood for fuel according to its relative value to society. Thus, roundwood that is appropriate for timber products will be used as such rather than as fuelwood in those instances when the fuelwood market cannot outbid the timber products market.

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[1] Italicized numbers in parentheses refer to items in references at the end of this report.

[2] Hereafter referred to as the energy policy.

Fuelwood takes many forms: some are wastes or residues, thinnings, rough, or cull material. Timber mills, furniture manufacturers, and others who manufacture wood products often burn the wastes for inhouse energy generation which helps eliminate what were formerly solid waste disposal problems. Private woodland owners can generate fuelwood by using their cull removals and thinnings from timber stand improvement (TSI) practices. If removals are sold, this also helps displace all or some of the TSI costs. A recently instituted cost-sharing program of USDA's Agricultural Stabilization and Conservation Service aims to produce firewood from material gained through TSI. As a by-product of TSI operations, the quality of wildlife habitat is improved as new mast and browse sprout become established, thus providing more food to wildlife.

WOOD'S ROLE IN THE NATIONAL ENERGY PICTURE

A century ago, the United States consumed almost four quadrillion (four quads or Qs) British thermal units (Btus) of energy per year, with 73 percent derived from wood (*101*). By 1900, wood energy, its importance greatly diminished, supplied only one-fifth of the total national energy demand. Only 1 percent of all domestically produced energy was believed to be derived from wood by 1976 (*101*). More recent estimates for New England will be derived from the New England Fuelwood Study.

Energy Dependence

The advent of oil and natural gas supremacy in world energy production rendered many nations, including the United States, dependent on these unequally distributed and nonrenewable energy sources. The New England Federal Regional Council (NEFRC) estimated that the United States annually consumes 67.933 Qs. Surprisingly, over 50 percent of the generated Btus are lost through processing, delivering, and other production steps (table 1). The total energy consumed that was obtained from imported fuel equaled 13.268 Qs, nearly one-fifth of the 1975 U.S. energy consumption (*82*). Today, imported oil supplies about 45 percent of the Nation's energy requirements, with New England receiving approximately 80 percent from foreign imports.[3]

Estimates of historical energy consumption differ due to different assumptions and methodologies. The U.S. Department of Transportation estimated that the United States consumed 75 Qs in 1973 (*34*) which conflicts with a lower 1975 estimate of 67.9 Qs postulated by the NEFRC (*82*). Projected national power needs for 1985 also differ. Some reports estimate that as few as 88 Qs will be necessary while others estimate a national energy con-

[3]Source: Massachusetts Office of Energy, telephone conversation, July 26, 1979.

sumption of 116 Qs (*34*). These figures illustrate the hazard of making projections in times of both raw resource and political instability.

The six New England States consumed 2.78 Qs in 1975, with only 15 trillion Btus generated within the area from hydroelectric and nuclear facilities (see table 1). Thus, more than 99 percent of the energy requirements supplied came from outside the region. Estimates of New England's 1985 energy requirements range from a low of 3.6 Qs with high energy conservation (*82*) to a high of 7.5 Qs (*15*). The projected 1985 consumption of 7.5 Qs is more than 2.5 times the 1971 level. Although this is an apparently high estimate, it only assumed an oil cost of $11 per barrel. The price of oil in late 1979 ranged between $24 to $34.50. Unless New England discovers new sources of energy, the standard of living will probably decrease as budgets are realigned to pay for increased energy costs, and as increasing energy costs curtail continued industrial and commercial development.

Wood is one alternative energy source. Other alternatives include nonrenewable fuels such as nuclear (with present technology application), coal, and geothermal as well as renewable energy resources such as solar, hydro, tidal, wind, and biomass (including wood). A fuel's renewability is a key asset when investigating alternative sources, though all energy forms do have some disadvantages (table 2).

National Use of Wood Residues for Energy

Houghton and Johnson's (*49*) reply to a *New Yorker* magazine article (March 25, 1974, issue), which stated that wood would remain the main source of energy for the majority of the population in the world, suggested that a maximum of only 0.4 percent of the U.S. energy needs could be supplied from wood residues. However, their analysis assumes that surplus annual growth is economically inaccessible and that only residues from timber harvesting and mill production are available. But as relative prices change, so might raw product allocation. Their analysis was also limited because they assumed that the wood would be converted into alcohol rather than various solid wood forms (pellets, chips, sawdust) for direct burning. Converting wood to liquid alochol involves much higher costs per Btu than direct burning (*46*).

Ellis (*35*) does not anticipate that wood residues will be available as a major new fuel source because of increased demands for processing them into onsite fuel and reconstituted products. Mills do not, however, use 100 percent of their residues, and excess wood residues that cannot readily be utilized may present storage difficulties. In this case, excesses would become available to other users. Using U.S. Forest Service national supply estimates, Ellis concluded that if all waste—mill (1.6 billion cubic feet), logging (1.6 billion cubic feet) and residues, tops, branches, and all

Table 1—Energy generation by source, energy consumption by sector, New England, 1975

Production or consumption type	United States		New England	
	Trillion Btus	*Percent*	*Trillion Btus*	*Percent*
Electrical production:				
Imported electricity	NA	NA	14.3	1.9
Hydro-electric	1,042.6	5.7	15.0	2.0
Nuclear	1,901.9	10.5	219.0	29.8
Coal	8,794.5	48.5	46.0	6.3
Natural gas	3,226.5	17.8	2.5	.3
Natural gas, liquid (NGL) and oil	3,167.2	17.5	438.2	59.6
Total	18,132.7	100.0	[1] 735.0	100.0
Losses	12,206.9	67.3	505.8	68.8
Net used	5,925.8	32.7	229.3	31.2
Residential consumption:				
Electricity	2,085.8	20.1	90.9	14.0
Natural gas	5,120.7	49.4	140.7	22.0
NGL and oil	3,155.8	30.4	412.8	64.0
Total	10,362.3	99.9	644.4	100.0
Losses	2,506.9	24.0	156.3	24.2
Net used	7,855.3	76.0	488.1	75.8
Commercial consumption:				
Electricity	1,602.3	23.0	74.7	14.0
Coal	156.6	2.0	.7	0.0
Natural gas	2,458.0	35.0	63.2	12.0
NGL and oil	2,872.4	40.0	392.0	74.0
Total	7,089.3	100.0	530.6	100.0
Losses	1,718.1	24.0	131.0	24.6
Net used	3,571.2	76.0	[2] 399.7	75.4
Industrial consumption:				
Electricity	2,237.7	11.6	63.8	23.1
Coal	3,138.8	16.2	3.9	1.4
Natural gas	8,956.6	46.2	52.9	19.1
NGL and oil	5,013.5	26.0	155.9	56.4
Total	19,346.6	100.0	[3] 276.5	100.0
Losses	7,735.0	40.0	70.4	25.4
Net used	11,611.6	60.0	206.0	74.6
Transportation consumption:				
Natural gas	594.9	3.0	.6	0.0
NGL and oil	18,333.1	97.0	823.7	100.0
Total	18,928.0	100.0	824.3	100.0
Losses	13,637.7	72.0	592.3	71.8
Net used	5,290.2	28.0	232.0	28.2
Total energy lost	37,804.6	55.6	1,455.7	52.0
Total unergy used	30,128.4	44.4	1,325.9	48.0
Total energy input	679,330.0	100.0	2,781.6	100.0

NA = not applicable.

[1] 735.1 source tally. [2] 399.6 source tally. [3] 276.4 source tally.

Source: (*82*).

Table 2—Advantages and disadvantages of energy sources to Maine

Source	Advantages	Disadvantages
Coal	Abundant and readily available in United States Leading source of electrical energy plants in country Inexpensive	Not available in Maine Fouls air Burning accounts for 75 percent of sulfur dioxide pollutants causing destruction of tracts of timber, especially pine, birch, elm and poplar Nonrenewable resource Mining disrupts land and can pollute streams
Oil	Power plants designed to use oil Fairly clean burning	Must be imported to Maine Expensive Nonrenewable resource
Nuclear	Does not pollute air Does not produce noxious odors Sites are clean Potential to yield enormous energy	Known reserves are limited Safeguards are elaborate Breeder reactors have not yet been developed that would consume present fission waste Nonrenewable resource
Hydro	Abundant and available in Maine Clean Renewable resource	Consumes vast tract of land that may be timber producing May destroy fish and wildlife habitat such as deer yards and spawning grounds Fluctuating shoreline is not aesthetically pleasing and is damaging to fishery Generally only used for peaking
Tidal	Readily available in Maine Renewable resource Clean	May supplant other industries such as refineries and free ship passage May be environmentally degrading
Wood residues	Renewable resource Can also burn coal and municipal solid wastes Readily available in Maine	High cost of collection in woods and transporting Accurate assessments of the actual amount of types of forest residue generated are unavailable.

Source: *Alternative Energy Sources of Maine*, a position statement prepared by the Maine Society of Professional Engineers, 1976.

nongrowing stock material at or larger than 4 inches in diameter (2 billion cubic feet)—had been collected in 1970, it might have supplied 7 percent of the U.S. fuel requirements for steam electricity. Primary and secondary costs would have eliminated much of the wood's accessibility. Although there is some energy in roots, stumps, stems, branches, and leaves, acquiring this material

would have made its use too expensive to compete with coal in 1970.

The reuse of plant byproducts or mill residues for other fiber products has risen substantially; sizable reduction in logging residue volumes are anticipated (*45*). Fifteen percent of the total 1970 pulpwood output in the Northeast supply region came from 75,739,000 cubic feet (591,711 cords)[4] of reused mill residues (*119*). The pulp and paper industry presently receives 31 percent of its total input from manufacturing wastes and only 4 percent from logging residues (*2*). In 1976, 25.5 percent of the total pulpwood output in the Northeast came from reusing 1,773,100 cords of residue. During this same year, New England used 3,882,600 cords, 18.1 percent of which was from residues (703,300 cords) (*16*). Mill, not logging, residues are in significant demand, since the latter can cost 10 times the price of manufacturing residues due to added collection, processing (such as chipping), and transportation costs (*2*).

Estimating residue availability poses some problems. Two different national estimates suggest that 130 to 149 million ovendry tons (ODTs)—approximately 20 percent moisture—of unused residue (*99*) and 120 million ODTs[5] of forest residues are available per year (*2*). Either volume estimate signifies important energy supplies. As usage increases, more reliable supply data will be necessary.

New England's Use of Wood Residues for Energy

One source indicates a sufficient amount of wood in the region to provide an energy equivalent to 21.3 million barrels of oil per year (*82*). This oil is equivalent to 7.5 million ODTs of wood based on NEFRC data. Bones estimated that 8.5 million tons of wood and bark residues primarily from logging residues and land clearing operations are available in the region (table 3) (*15*). Bones also calculated an energy equivalent of 147.5 trillion Btus derivable from these 8.5 million ODTs (table 4) (*15*). Thus, according to Bones, wood residues resulting from logging residues and land clearing could potentially supply an equivalent of more than 24 million barrels of oil. Another study undertaken by the New England Energy Congress estimated that burning residues as well as other solid wood would result in a savings of 55 million barrels of oil by the mid-1980's (*81*). Given today's price range per barrel of oil ($24 to $34.50), Bones' estimate is an equivalent of $576 to $828 million, while the Energy Congress' estimate would equal $1.32 to $1.9 billion in gross savings.

Birkeland also estimated the energy potential that the New England wood resources could supply as being equivalent to four

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[4] 1 cord = 128 cubic feet.

[5] Assumes an average of 40 pounds per cubic foot for softwood and hardwood.

Table 3—Volume of potential fuel made available by land clearing in New England, 1973

State	Forest land cleared during 1973	Above-ground biomass[1]			
		Total		Available[2]	
		Wood	Bark	Wood	Bark
	1,000 acres	*1,000 ovendry tons*			
Connecticut	17	547	80	496	73
Maine	14	536	78	404	59
Massachusetts	27	797	117	723	106
New Hampshire	11	318	47	267	39
Rhode Island	4	82	12	74	11
Vermont	4	96	14	81	12
Total	77	2,376	348	2,045	300

[1] Includes bole, top, branches, and stump of all standing trees 1 inch diameter breast height (DBH) and larger.

[2] Growing stock volume recovery factor assumed to be 0.5 for Maine, 0.33 for New Hampshire and Vermont, and 0.2 for Southern New England.

Source: (*15*).

Qs, or 14.1 percent of the 1975 energy needs (*9*). But this estimate appears much higher than present use and trends suggest. In any case, the differences between the estimates suggest a need for a comprehensive and consistent data gathering plan. Analysis must reflect not only gross amounts of wood present, but also the amounts of wood available for the many existing and potential demands.

New England used 12.6 million cubic feet (mcf) (or 252,000 ODTs—13.4 percent of its manufacturing residues) for fuel in 1973 (*15*). Using NEFRC data, this volume of wood is equivalent to nearly 716,000 barrels of oil. Residues generated in New England's primary manufacturing plants (excluding pulp mills) exceeded 94

Table 4—Volume of wood and bark residues and gross energy value, New England, 1973

Source of residue	Residues		Energy value[1]	
	Wood	Bark	Wood	Bark
	Million ovendry tons		*Btu* x 10^{12}	
Timber harvesting	4.6	0.9	78.2	17.1
Primary manufacture	0.2	0.3	3.4	5.7
Secondary manufacture	0.2	NA	3.4	NA
Land clearing	2.0	0.3	34.0	5.7
Total	7.0	1.5	119.0	28.5

NA = not applicable.

[1] Assuming 17 million Btus per ODT of wood and 19 million Btus per ODT of bark.

Source: (*15*).

mcf in 1973; 84 mcf were used. Some 42.8 mcf of that 84 million were chipped for constituted fiber products (*15*). In 1977, residues from manufacturing plants were equivalent to 98.5 mcf (*13*). Thus, residue production and use is quite significant, constituting over 34 percent of the total source volume of pulpwood production. As demand for fuelwood increases, the potential for competition between fuel and other uses increases. Thus, as the market allocates between these uses, increased prices will probably result.

WOOD AVAILABILITY AND TECHNOLOGY

Particular technologies often affect wood availability for fuel. In some parts of the country, for example, wholetree harvesters are used to harvest stump and roots, in addition to harvesting the above-ground material. Technology adaption at lumber mills and pulp mills also affect volumes available for wood fuel.

Residue Supply

Five factors help estimate residue supplies:

1) Only about 50 to 60 percent of a log entering a logging or plywood mill becomes a primary product; the rest is residue (*29, 100*). These figures are based on Pacific Coast mill recovery rates which are higher than those for mills in New England. Although there is more residue in the Pacific Coast than elsewhere in the country, the Pacific Coast region uses at least 90 percent of its wood residues and 70 percent or more of its bark residues (*50*).

2) The percentage of mill residues recovered in New England is fairly high, ranging from 77 percent in Massachusetts to 86 percent for Connecticut and Rhode Island (table 5) (*15*).

Table 5—Volume of manufacturing residues used in New England

State	Type of use				Proportion of residues used
	Fiber	Fuel	Other	Total	
	Million cubic feet				*Percent*
Connecticut	0.3	0.3	1.2	1.8	86
Maine[1]	26.7	8.4	13.8	48.9	82
Massachusetts	2.6	.7	2.4	5.7	77
New Hampshire	8.9	1.3	6.3	16.5	85
Rhode Island	.1	.1	.1	.3	86
Vermont	4.5	1.8	4.4	10.7	84
Total	43.1	12.6	28.2	83.9	NA
	Million ovendry tons				
Total	.6	.2	.4	1.2	NA

NA = not applicable.

[1] Maine is updated to 1973 data.

Source: (*15*).

3) Although Southern New England (Massachusetts, Connecticut, and Rhode Island) had only about 3 mcf of logging residue in 1971, over 60 mcf of timber was cut in land clearing operations and either burned or buried (*83*). Thus, a staggering amount of wood residue was inadequately reported, accounted for, and recovered from land clearing. Wood from cleared lands is a now or never opportunity to obtain valuable wood that is otherwise burned uselessly at the harvest site or constitutes a serious solid waste disposal problem. Massachusetts, which used the least mill residue in 1973, also cleared more forest land than any other State in New England—27,000 acres of a regional 77,000 acres cleared. Massachusetts disposes 1.3 mcf of mill residues, and 12.2 mcf of wood from cleared land each year (*95*). The Southern New England States lost an average of 35,000 acres of commercial forest land per year during 1952-71 due to changes in land use, according to Kingsley (*61*). These States are expected to continue to lose more forest land, as will the remainder of New England. Kingsley predicts, however, that the land clearing rate for these three States will decline by 1,000 acres each year from the 1952-71 rate.

4) Few States have reliable data on nongrowing stock residue which makes estimating regional and national residue supply difficult (*50*). The Forest Service records growing stock timber volumes and residues according to the merchantable bole concept[6] and the commercial species in a given stand. Residue estimates are computed by compiling volume data on those trees which do not meet established criteria of growing stock in each plot measured. However, dead and down trees in the plot are not measured. Thus, the criteria used does not adequately measure the nongrowing stock.

5) Forty percent more softwood fiber and 100 percent more hardwood fiber may be attained by harvesting the above-ground components of cull, dead small diameter (less than 4 inches) and weed trees. Using chip harvesters and the complete tree concept[7] more often could yield substantially more residue (*50*), although this concept has drawbacks, too.

New England Timber Resource

In 1970, 83 percent or 32,367,000 acres of New England's 40,314,000 total land acres were officially designated commercial forest land. In 1977, this figure was 77 percent[8] (table 6) (*119*). If

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[6] The merchantable bole is that volume of wood (board or cubic feet) measured beginning at least 1 foot above the ground at the point where the main or central stem measures at least 5 inches in diameter (measured on the outside bark), extending upward to the point where the diameter of the main stem first measures 4 inches (measured on outside bark). The volume is that material between these two points.

[7] See glossary.

[8] Although the figures represent only commercial forest land acreage, the classification primarily under discussion here, an additional 284,000 and

Table 6—Land areas in New England, January 1, 1970

State	Total land area	Forest land			
		Total	Commercial	Productive reserved	Unproductive
	1,000 acres				
Connecticut	3,116	2,186	2,169	11	6
Maine	19,797	17,748	16,894	220	633
Massachusetts	5,013	3,520	3,491	18	11
New Hampshire	5,781	5,131	5,020	23	88
Rhode Island	671	433	429	4	0
Vermont	5,935	4,391	4,364	7	20
Total	40,314	33,410	32,367	284	759

Source: (*119*).

Connecticut, Massachusetts, and Rhode Island typify the growth characteristics of the region's forests, then over 9 percent of all softwood trees and more than 11 percent of all hardwood trees in New England are rough and rotten. Annual softwood mortality is almost 9 percent of the gross growth; over 13 percent and 7.5 percent of gross growth volume of softwoods and hardwoods, respectively, are culled each year (*61*).

Ownership of the timber resource greatly influences the accessibility to wood. Forest land in New England is largely held by private owners. At least 56 percent of the total land area of each State is classified as commercial forest land (table 7). As much as 99 percent and no less than 87 percent of the commercial acreage

Table 7—Commercial forest land and ownership

State	Land area in commercial forest land	Forest land privately owned[1]	Commercial forest land owned by forest industries
	Percent		
Connecticut[2]	58	92	0.1
Maine[3]	85	99	49.0
Massachusetts[2]	56	87	1.0
New Hampshire[4]	81	87	20.0
Rhode Island[2]	59	92	NA
Vermont[5]	73	[6]90	NA

NA = not applicable.
[1] Including forest land owned by forest industries.
[2] Constructed from (*61*).
[3] Constructed from (*36*).
[4] Constructed from (*60*).
[5] Constructed from (*119*).
[6] Constructed from (*66*).

759,000 acres of forest land are classed as "productive-reserved" and "unproductive," respectively. For exact definitions of forest land class distinctions, see glossary.

in any one State is privately owned. Roughly 184,100 private owners (corporations, partnerships, associations, and private individuals) own the commercial forest land in the three Southern New England States (*59*). The multitude of these private owners complicates accessibility and determination of timber supplies, particularly in Maine. Maine has a unique ownership system where land is often held by an uncountable number of parties each having "common and undivided interest" in a specific parcel of land. The owner may choose to leave an undefined fraction of land—undefined because by law, it is held commonly and indivisibly with other owners—to several coparceners, further fragmenting ownership (*36*).

Only 4 percent of the owners in Southern New England (holding 8 percent of the forest land) bought or now own their land primarily for timber production. But there are many other reasons for owning forest land. Thirty-nine percent of the owners consider their forest land part of their residence, which accounts for 27 percent of forest land acreage. Land investment and recreation were equally the second most common reasons for owning forest land (17 percent of the private owners chose each reason). Nearly 88 percent of the present forest land owners in Southern New England have never harvested their wood. Since they are not recent owners, most having had their land for over 10 years, the no-harvest stance may not change in the near future (*59*).

Neal Kingsley calculated that forest land owners of Southern New England could permit the annual harvesting of between 50 and 90 mcf of roundwood (*59*). However, three factors, over time may result in a different estimate. These factors are:

1) The volume of poor quality (rough, rotten, dead, diseased, crooked) timber on commercial forest land is enormous. Eighty percent of the commercial forest land in Southern New England has reached or surpassed its optimum growth. This forest land is fully if not overstocked. Yet the percentage of stands fully stocked by growing stock quality trees drops to only 46 percent of all stands when volumes of rough and rotten trees are excluded. Thus, 34 percent of all forest land in the region is so laden with rough and rotten trees that those stands cannot be considered optimally stocked (*61*).
2) Substantial volumes of wood fiber need to be harvested from the region's forests to upgrade the timber stand quality. An estimated 228,455.8 mcf of softwood and 385.493.0 mcf of hardwood should be removed each year (table 8). These figures were derived by calculating annual mortality, desired annual thinnings and removals of new growth in topwood, and the volumes of rough and rotten wood in sound timber stands that should be removed. One report found that approximately 13 percent of all New England trees in forest land are rough and rotten (*83*).

Table 8—Recommended wood fiber removals from New England forests

State	Softwood	Hardwood
	1,000 cubic feet	
Connecticut	5,500.6	39,195.0
Maine	112,693.2	109,046.0
Massachusetts	17,895.7	62,577.0
New Hampshire	39,945.9	78,674.0
Rhode Island	1,238.9	8,048.0
Vermont	51,181.5	87,953.0
Total	228,455.8	385,493.0

Source: Edward Sprague, U.S. Forest Service Portsmouth, NH, July 21, 1977 letter to Stephen G. Twombly on the supply of wood for fuel.

Moreover, Vermont has a higher percentage of culls than does the rest of the region (25 percent) (*83*).

3) TSI techniques, such as cull removal, can pay for themselves within a few years through increasing quality and quantity of sawtimber yields (*126*). Vermont could increase its current average net growth at least 300 percent by removing culls. Harvests there could be quadrupled without harming the forest environment if a market were developed for poor quality wood (*66*). Harvest volumes must increase to reverse the detrimental effects of low harvests on volumes of quality sawlogs. Continued low removals are apt to negatively affect the future forests, species mix, and environment (*61*).

Owners can financially benefit from harvesting timber by increasing their timber stand value through thinning out culls; increasing the volume and quality of their sawtimber yields and then allowing the sawtimber to be harvested; selling poor quality wood as fuelwood, or to mulch, paper or other forest industries; and allowing new growth through harvesting of mature, sound timber. Such practices will have a side benefit in that mast and browse will increase, thus providing better wildlife habitat.

Though uninformed landowners might only free 50 mcf of roundwood, knowledgeable landowners may be willing to cut vastly more wood for fiber and/or fuel. As demand for fuelwood continues, the no-cut stance of many forest land owners may change, especially if TSI costs can be covered by revenues generated by selling cull wood as wood fuel.

Demand for Wood

In general, normal forest areas must satisfy the multiple needs of many constituents. Wood demand for manufacturing and construction on a national basis is expected to surpass future supplies (*63*, *49*, *35*). Although there is disagreement as to the year this

shortage will occur, Lassen and Hair predict that by 1980 wood supplies will fall 2.5 billion cubic feet below demands (*63*). Serious wood fiber competition is forecasted by Houghton and Johnson (*49*). These two authors, using U.S. Government data, estimate that by the year 2000, forest product demand will increase between 50 and 200 percent from 1970 demand levels. The Forest Service (*119*) projects that roundwood use at present prices will reach 23 billion cubic feet (an increase of 81 percent from 1970) by the year 2000, with the largest increase in demand for hardwood species. However, when the projected increases in price are applied to demand projections, total timber demands for the year 2000 decline to 19 billion cubic feet.

Forest Service specialists feel that the availability of both softwood and hardwood is tightening. Wood fiber demands will apparently soon outstrip wood supplies. These supply and demand discrepancies for wood will be balanced by rising timber prices. New England currently lacks quality sawtimber for specialized products but has a surplus of poorer wood for products such as railroad ties and pallets. Annual removals will exceed net growth volumes of U.S. forests (softwood and hardwood) shortly before the year 2000, given the 1970 levels of management and certain area cutting assumptions (*119*). The NEFRC report envisions changes in forest management practices that will help correct timber supply shortages (*83*). The threat that removals are nearing growth may be beneficial if expected price rises motivate forest land owners to increase management on their forest land. If so, the narrowing supply-demand trend could be reversed or at least slowed.

Fuelwood Demand

The use of wood for heating has been rising, spurred by the 1973-74 oil embargo. The United States consumed an estimated 16 million cords of fuelwood in 1970 (*119*). Growing stock roundwood supplied approximately 25 percent of recorded fuelwood consumption. Roundwood from other sources (such as dead and cull trees) supplied 2.9 million cords (18 percent) and the remaining 57 percent of total recorded fuelwood consumption came from reused primary plant residues (*119*). Maine's fuelwood production rose from 264,000 cords in 1958 to 324,000 cords in 1970 (*17*).

Recent surveys in some of the New England States attest to the increased residential demand for fuelwood (*8*, *31*, *61*, *83*, *109*, *112*, *119*, *121*). A survey in Franklin County, Mass., concluded that 48 percent of the residents burn wood. Collectively, they consumed 38,000 cords of firewood during the 1977-78 winter, which represented a 23-percent increase in domestic firewood consumption in just one heating season. Of the wood-burning residents, 42 percent claim wood as their major heat source. Just over half the users cut all their own fuel, 29 percent bought all their

wood fuel, and 18 percent purchased part of their supply (*109*). In recent years, demand for cut firewood has apparently surpassed supply after the onset of winter. Most respondents (66 percent) to the Franklin County survey would have bought more wood if it were available or better seasoned than what they could get. Eighty-four percent said they were willing to buy wood in spring or early summer for the comming winter to ensure an adequate supply.

A 1977 New Hampshire survey concluded that 52 percent of the households burned wood. Most users (69 percent) cut all or part of their own supply. Statewide residential demand for fuelwood was 300,000 cords. Two-thirds of the fuelwood consumed was cut by the users themselves and the remainder was purchased. For the 1976-77 winter, the total dollar value of the fuelwood purchases was nearly $4 million (*31*).

A 1976 survey in Vermont concluded that those who used wood as a sole heating source increased from 1 percent of all households to 6.7 percent during 1970-76 (*8*). Over half of all Vermont residences supplement their heating with wood. Of the approximately one-third homeowners who use wood stoves, over 60 percent of the wood stoves were installed within the last 3 years of the survey.

A 1978 followup survey used a questionnaire very similar to the one in 1976 (*121*). During the period between the surveys, a number of changes occurred. Use of wood stoves rose from slightly less than one-third of Vermont's households to 42 percent. While those households which burned wood increased from slightly more than half to two-thirds, the percentage of households that used wood as the primary heating fuel increased from 6.7 percent in 1976 to 18 percent in 1978. In addition, 31 percent of those burning wood used 5 or more cords, up from 19 percent in 1976.

The Maine Audubon Society conducted a statewide survey to gauge present and projected residential demand for firewood (*67*). The survey concluded that 46 percent of Maine homeowners burned 468,000 cords of firewood during the 1977-78 winter. In addition to conducting demand surveys, the Audubon firewood study is looking at how the increased use of firewood would affect the forest resource, and is developing a handbook on firewood usage, woodlot management, marketing wood, and available forestry services.

At least 30 percent of New England homes use wood-burning stoves for supplemental heat. Those homes which use combination wood-fired furnaces receive about 50 percent or more of their heat from wood (*122*). Maine, which has ample wood, runs out of seasoned, cut cordwood each winter. One forester cautioned that in Vermont, one would be lucky to find any wood at all to buy after January, and what would be available would probably not be seasoned and cost somewhere between $70 to $80 per cord; today, that amount is probably much more. A significant proportion (64 percent) of the fuelwood in the three Southern New England States came from growing stock supplies of roundwood.

The amount of heat derived from cordwood is a function of the density of the species and the moisture content. With higher density wood, there are more pounds per cord than lower density wood. Hardwood species are the most desirable to burn and have the greatest available heat per unit of volume (table 9). Wood should be seasoned (dried) before burning in order to maximize heat recovery rates. Table 10 summarizes the characteristics of many wood species. Currently, most timber demand is for softwood varieties; hence in those areas with a relatively large mix of specie types, competition between uses has not yet reached a crisis state. In areas predominantly stocked in softwood, demand between products could potentially pose serious problems, unless residue from timber products industries could supply much of the fuelwood demand. Although demand for softwood is nearly seven times greater than hardwood demands (*119*), location of the stands and their mix determine in large part the future competition between uses. Estimates of these potential demand conflicts are required. Location of present plants should be identified, and source locations of raw products should be correlated. In addition, a geographical distribution of hardwood and softwood locations should be identified and overlayed among fuelwood and timber products consumption areas. Such an endeavor would be a first step in identifying future conflict areas.

Industrial use of wood energy has also increased. One report shows that 230 hogged fuel boilers were sold in the United States

Table 9—Heat equivalents of common wood species

Species	Weight[1]		Available heat units per cord[2]		Equivalent gallons of fuel oil per cord of wood[3]
	Green	Air-dry	Green	Air-dry	
	Pounds		*Million Btus*		*Number*
Ash	3840	3440	16.5	20.0	119
Aspen	3440	2160	10.3	12.5	74
Beech	4320	3760	17.3	21.8	130
Paper birch	3800	3040	16.7	18.3	108
Yellow birch	4560	3680	17.3	21.3	127
Elm	4320	2900	14.3	17.2	102
Hickory	5040	4240	20.7	24.6	146
Soft maple	4000	3200	15.0	18.6	111
Hard maple	4480	3680	18.4	21.3	127
Red oak	5120	3680	17.9	21.3	127
White oak	5040	3920	19.2	22.7	135
White pine	2880	2080	12.1	13.3	79

[1] Per standard cord (4′ by 4′ by 8′) containing 80 cubic feet of solid wood.
[2] Moisture content approximately 20 percent.
[3] Using air-dry wood at 50-percent heating unit efficiency, oil 65 percent.

Source: Stanley Gutkowski, *Buying Firewood, Volume and Value*, Berkshire-Franklin Resource Conservation and Development Area, Sunderland, Mass., June 1978.

Table 10—Firewood ratings

Type of wood	Relative amount of heat	Easy to burn	Easy to split	Heavy smoke	Does it pop or throw sparks?	General rating and remarks
Hardwood trees:						
Ash, red oak, beech, birch, hickory, hard maple, pecan, dogwood	High	Yes	Yes	No	No	Excellent
Soft maple, cherry, walnut	Medium	Yes	Yes	No	No	Good
Elm, sycamore, gum	Medium	Medium	No	Medium	No	Fair—contains too much water when green
Aspen, basswood, cottonwood, yellow-poplar	Low	Yes	Yes	Medium	No	Fair—but good for kindling
Softwood trees:						
Southern yellow pine, Douglas fir	High	Yes	Yes	Yes	No	Good but smoky
Cypress, redwood	Medium	Medium	Yes	Medium	No	Fair
White-cedar, western redcedar, eastern redcedar	Medium	Yes	Yes	Medium	Yes	Good—excellent for kindling
Eastern white pine, western white pine, sugar pine, ponderosa pine, true firs	Low	Medium	Yes	Medium	No	Fair—good kindling
Tamarack, larch	Medium	Yes	Yes	Medium	Yes	Fair
Spruce	Low	Yes	Yes	Medium	Yes	Poor-but good for kindling

Source: (*116*).

between 1965 and March 1975 (*83*), while a second estimates that within the last decade, 250 wood-fired boilers were sold for industrial use (*7*).

Industrial demands for wood fuel are more difficult to quantify. On a small scale, the Vermont State Hospital in Duxberry (*123*) requires 45 tons of chipped wood daily at a moisture content of 40 to 50 percent to produce 10,000 pounds of steam, or 9.75 million Btus per hour at maximum capacity. Comparing heat costs for the hospital, coal alone was found to be a less expensive fuel than wood (an average of 20.9 cents vs. 21.5 cents to heat each square foot of the hospital). On a much larger scale, 350 square miles of softwood forest would be required to produce enough wood on a sustained basis to supply a kraft pulp mill which uses 1,000 tons of pulp per day (*111*). The same forested land area could support a 400-megawatt (MW) wood electricity plant.

Maryville College in Tennessee evaluated the advantages of large-scale conversion to wood fuel (*112*). Annual fuel costs were itemized for oil and natural gas consumption by the college since 1972. Despite conservation measures which cut overall energy use by nearly 40 percent, the college's fuel bills rose 111 percent during 1972-76. An estimated 5,961 tons of residue at most would be required per year if the college heating system were run on wood. Net savings from converting to wood energy were expected to exceed $1 million within one decade.

Numerous wood-powered generators have been designed for industries. The investment of converting a drying kiln to wood fuel can be repaid in less than 2 years (*87*). Once converted, lumber can be dried using 500 pounds of planer shavings for fuel in lieu of 1,600 cubic feet of natural gas. The moisture content of the proposed wood fuel can significantly influence the feasibility of wood energy conversion, however, because water in wood supplies severely diminishes the quantity of recoverable heat. A lumber company illustrates this point: steam output was increased nearly 200 percent from 66,000 to 112,000 pounds per hour when dry wood fuel was substituted for wet (*60*). It is also environmentally more desirable to burn dry wood because particulate emissions are not as high.

TYPES OF WOOD FUEL

Wood fuel takes many forms: standard cordwood, which comes in whole and split logs; coarse residues (slabs, edgings, and chips); fine residues (planer shavings and sawdust); logging residues (chipped or shredded); TSI removals of cull wood; and chemical liquors such as methanol, ethanol and furfural. Other than the chemical liquors, these residues can be pulverized, dried, and pressed into small wood fuel pellets. The determinants of converting to these different forms are the types of burners that can utilize them, the different energy values, and the costs of processing wood into the particular fuel form.

Cordwood

Cordwood is the most common wood used in domestic fuelwood consumption. Although the energy content of wood ranges from 15 million (*101*) to over 39 million (*83*) Btus per standard cord, depending on species (weight per cord), the amount of energy in an ovendry pound of wood is about the same for almost all species (*101*). One cord of mixed hardwoods, unsplit and undelivered, was the least expensive ($1.68 per million Btus) of several fuels priced by the New England Federal Regional Council (*83*). This price translates into approximately $30 per cord, assuming a 60-percent conversion efficiency. In east central Vermont, the Resource Conservation and Development (RC&D) Forestry Committee's 1977 fuelwood questionnaire found that average fuelwood prices ranged from $10 for logs, tops, and the like to $70 for dry, split and delivered wood per cord (conversation with Kling Wigren, former Resource Conservation and Development forester, east central Vermont RC&D area). These prices include stumpage prices from $0 (as part of logging cleanup operations) to $8 to $10 per cord; getting the logs on the landings, $10 to $20 per cord; bucking costs of $7 to $10 per cord; splitting costs of $5; and delivery costs of $7 to $10 per cord. One man in Pennsylvania sells his wood for a remarkable $120.50 for a split, delivered, seasoned standard cord, or equivalent. The price for customers picking up the wood is $93.50. Profit per cord (excluding office expenses) is approximately $36 (*57*). This is an exceptionally high price, but as mentioned earlier, even Maine residents pay $75 or more for a cord of wood in the winter months.

Chipped Wood

Chipped and hogged wood, residues, culls, and pellets can be used as feed for gasification systems, steam electric generators, boilers, furnaces and drying kilns. The NEFRC considers chips and pellets the most efficient forms of wood fuel for nearly all types of burners. Bark chips have greater energy values than wood chips—9,000 to 10,000 Btus per dry pound of softwood bark (slightly less for hardwood bark) as opposed to hardwood chips at 8,000 to 8,500 Btus per dry pound, and softwood chips at 9,000 Btus per dry pound (*29*).

Residues

Residue prices vary according to the extent of processing. Raw bark and green shavings cost as little as $4 per ton, undried, in 1974. Chipped and debarked mill residues cost $9 to $10 per ton. Bagging, drying, or baling residues increase market prices, too. For example, the highest priced residues in 1974 were bagged dry shavings at $57.50 per ton (*100*). Cull wood in Vermont sold for

$29.50 per delivered cord in 1975. Itemized expenses were $21 for harvesting, $1 for stumpage, $4 for chipping, and $3.50 for transportation (*7*). Pellet prices are also reasonable; an Oregon pellet plant manufactures 100 tons of pellets daily for $15 per ton and sells them at $22 per ton, f.o.b. at the plant. One ton of pellets has as much energy as 3 barrels of oil (*83*).

Chemicals From Wood

Chemical fuel derivatives from wood involve extensive technology, capital, and acreage to raise wood as a fuel crop. Chemical extraction usually occurs through a wood gasification process. Converting other substances to chemicals is more efficient than converting wood; coal is a more efficient parent of synthetic natural gas, and natural gas is a better producer of methanol than wood. The costs of obtaining chemicals from wood waste were so large that many such operations were infeasible in 1975 (*94*).

Charcoal

The University of Maine's Cooperative Forestry Research Unit investigated the conversion of low-quality timber into charcoal for domestic space heating as a means of developing new markets for low-grade hardwoods (*22*). The resulting report concluded that if charcoal were to capture 16 percent of Maine's total domestic space heating market, then one-half of the State's standing volume of low-grade hardwood could be used over an interval of 20 years. The report states that about one-half of the heat value for wood is lost during the conversion process to charcoal, assuming that steam is not generated to power some form of energy production process. Yet this loss is not a real loss unless a realistic opportunity exists for using the solid wood directly. The premise was that charcoal manufacturing was feasible for those areas so remote from potential fuel customers that the additional costs of transporting solid wood eliminated its advantage. Estimates of selected biomass conversion costs compared the ratios of capital costs per ODT of plant capacity to the ODTs of wood required per day. Charcoal manufacturing had the lowest ratios (ranging from 6.7 to 20.0) as compared to methanol production (ranging from 28.5 to 43.2), and electricity (31.5 to 64.7). Under recent technological advances, charcoal could probably be produced for $26 per ton, and a selling price of $52 per ton would not be unreasonable. The feasibility of charcoal production is based on being able to market the three main products resulting from the conversion process: charcoal, wood oil (similar to no. 6 fuel oil) and wood gases. Wood gas byproducts cannot be stored, so that unless an immediate use can be found for these gases (such as onsite electrical generation), the economic feasibility of charcoal conversion plants is negative.

WOOD FUEL AS AN ENERGY ALTERNATIVE

Wood can be used either directly as a solid, a processed fuel (chipped or pelletized, for example), or converted to other forms (alcohol or charcoal). Wood fuel for commercial applications may initially be more costly than other fuels. The capital investment required to build or convert a wood-burning plant is relatively high, sometimes double that of coal and gas-fired units (*2*, *32*). However, with the possible exception of coal in many geographical areas, wood for fuel can effectively compete with petroleum and electricity. Initial plant investment may be higher than the more commonly used fuels, but the relatively low cost of wood fuel permits low operational costs, hence a relatively competitive operation. Sarles cites a report that discusses five wood energy plant feasibility studies (*100*). The annual savings in fuel costs of residue-fired plants resulted in payback periods of 2 to 3.3 years; moreover, the study was conducted in 1973, when wood was not as competitive with other fuels as it is today. Arola estimated longer payback periods of 4 to 8 years (*2*). The significant point is that wood-fired plants are indeed competitive, but the limiting factors may be the assurance of long-term supply of wood fuel.

Domestic conversion to a complete centralized wood-heating system could require an initial investment of between $2,000 and $3,500 (*66*). Payback periods based on annual savings depend on the fuel prices being replaced and the cost of procuring usable wood fuel. Supplemental heat supplied by wood is much less expensive. Vermont households using wood as the primary source of heat increased from less than 7 percent to 18 percent of those households burning wood during 1976-78, a 157-percent increase (*121*).

Converting wood to chemicals (primarily alcohol) and then utilizing same to fire a heating apparatus is a more expensive proposition than heating directly with solid wood (*46*). However, if the value of convenience and the value of having a uniform fuel were entered into the equation, the competitive position may not be as negative as most suggest. More research is needed in this area.

Two other studies, one for Vermont (*123*) and one for Maryville College (*112*), found that wood fuel held a competitive advantage over natural gas and fuel oils. Only coal was shown to be more competitive in Vermont. But one of the possible benefits of utilizing wood fuel in Vermont is that the quality of the forest resource may increase as a result, a benefit not included in the analysis.

ENVIRONMENTAL IMPACTS

The presently low rate of timber removal in most of New England poses problems with regard to sawtimber quality and the forest environment (*61*). The majority of the region's forest land is highly dense (fully stocked) but of low quality. Forest resources

would benefit if removals were increased, especially the low quality and other cull stock. Consideration should be given, however, to the advantages and disadvantages of different harvesting techniques. A Vermont study of whole tree harvesting and clearcutting cautions that unless proper safeguards are employed, potential environmental problems may be aggravated:

> While selective cutting and logging according to good forestry practices on longer rotations can be carried out with minor environmental impact, modern mechanized harvesting systems are capable of clearing large areas rather rapidly. Without proper controls, such operations could result in significant environmental impacts by encouraging excessive clearcutting, inducing erosion, destroying wildlife habitat and accelerating the depletion of soil nutrients (*66*).

The study also states that whole tree utilization approximately doubles the rate at which nutrients are withdrawn from the forest.

Impact of Harvesting Wood

Several studies argued that there are bountiful supplies of wood available through collection of logging wastes (*15*, *29*, *66*, *83*). In 1972, an estimated 50 mcf or more of logging residues were left in the forests of Vermont and New Hampshire; as a rule, over 30 percent of all harvested trees were left in the forest (*83*). The nutrients in the top sections, which comprise most of what remains at the harvest site, are substantial. When tops are taken with boles, total nitrogen removal increases by more than 70 percent. Generally, this percentage of nutrient removal also occurs for calcium, phosphorus, magnesium, and potassium (*66*). Young (*130*) realized these consequences to nutrient levels when he developed the complete tree concept; he extended the concept so that nutrient levels would be maintained and erosion prevented by applying management practices.

Clearcutting followed by slash burning usually increases nutrient levels in nearby streams (*8*, *41*, *48*, *98*, *107*).[9] Logging road construction and failures pose serious problems with regard to erosion and subsequent sediment loads in waterways unless proper techniques are used (*41*, *75*). When nutrient ion concentrations and sediment loads increase in streamflows, the aquatic environment may suffer higher stream temperatures and channel blockages which have adverse effects on fish habitat as well as overall stream quality (*8*, *23*, *98*, *110*).

Forest land is noted for low levels of erosion compared with other land uses (*61*). However, clearcut harvesting potentially has a great influence on erosion rates (*80*). Clearcutting and subsequent erosion leads to much higher loads of sediment in streams. Those

[9] The burning of logging residues at the harvest site. It should be noted that slash burning is a declining practice due to either air quality standards or open burning restrictions.

sediment deliveries are considered one of the most serious pollution problems of forest land (*76*).

The nutrient levels in streams will decline as clearcut and burned areas become revegetated and absorb the nutrients that would have been delivered to streams (*41*). Selective harvesting or strip (rotation) cutting are harvesting alternatives to clearcutting. A study made at the Hubbard Brook Experimental Forest in New Hampshire found that when strip cutting was used rather than clearcutting, significantly lower nutrient ion concentrations occurred in streams. Thus, when the time span and cutting pattern vary, the adverse impacts of clearcutting can be minimized (*48*).

Harvesting forest lands can increase water yields to nearby watersheds by up to 41 percent (*47*, *48*, *80*, *98*). Logging and slash burning can increase water yields year round (*98*), but rotation cutting is necessary to maintain a somewhat constant water yield over time (*47*).

Impact of Burning Wood for Power

One of the most notable assets of wood energy, as with all solar-based fuels, is its renewability, but there are other advantages (*101*, *111*). Biomass burning appears to do less harm to the environment and atmosphere than fossil fuel usage since plant matter is essentially sulphur-free. The sulphur content of wood is between 0.01 and 0.05 percent, whereas oil and coal contain up to 3 percent sulphur or more (*101*). The residual ash from plant matter can be recycled back into the soil as a natural fertilizer, thus eliminating most ash disposal problems. Also, the problems of leakage, spillage, or unanticipated fuel explosions associated with oil, natural gas, and coal (*111*) are minimized.

Carbon dioxide production is a useful point of comparison for fossil fuels versus wood energy. Though not usually viewed as a pollutant, atmospheric levels of carbon dioxide play significant roles in the earth's climates. As these levels increase, the earth's ability to cool itself lessens because the infrared radiation normally released by the earth is reflected back by excessive carbon dioxide. Burning fossil fuels or biomass always yields carbon dioxide. The critical difference is that while wood gives off carbon dioxide as a natural byproduct of its decaying processes, fossil fuels have carbon dioxide trapped within, which would not normally be released except through burning (*101*). Thus, wood fuel does not appreciably alter the carbon dioxide balance in the long run (*101*, *111*). However, the levels of six air pollutants—sulphur dioxide, particulate matter, carbon monoxide, photo-chemical oxidants, hydrocarbons, and nitrogen dioxide—officially designated and monitored by the Environmental Protection Agency (EPA) could possibly be increased by burning wood.

Incomplete combustion is more likely with domestic burners. Industrial burners and boilers are closely regulated, making them more efficient and less polluting (*8*). The combustion efficiencies of

several domestic stoves depend on stove designs, such as the double drum stove which is more conducive to the complete combustion of volatile gases than others (*101*). Bedrosian summarizes this concern:

> Domestic (burners) are likely to involve thousands of point sources (of pollution) representing varied burning characteristics and for which uniform effective combustion and emissions control would be virtually impossible to achieve. . . However, air pollution from wood burning appears. . .to represent more of a problem from the undesirable effects of local meteorological conditions affecting pollutant distribution and oxidant formation than from the direct discharge alone (*8*).

Thus, as the trend of more domestic wood-burning stoves and furnaces continues, local air pollution problems may increase.

CONCLUSIONS

Since the oil embargo of the early seventies, New England has experienced a phenomenal growth in the use of wood as a supplementary or primary heating source for residences. Vermont wood now heats a State hospital and generates electricity in Burlington. Maine is presently investigating the possibility of generating electricity using wood as a primary fuel. These relatively recent changes have occurred for two reasons: the huge increase in petroleum prices since 1973 and the vast forest resource which covers approximately 80 percent of the region.

Past cutting practices (namely high grading) and a lack of historical forest land management throughout most of New England has resulted in a low quality resource. The low quality is also due to the fact that though much of the forest land is nearly fully stocked, the diameter of many of the trees is small, resulting in a lower grade. Thus, proper TSI applications would provide the necessary room to permit the smaller diameter trees to increase in quality over time. The removed wood could supply the fuelwood market, thus providing the revenues to finance the TSI practices. Until such practices are initiated, timber product demand will be low and thus the potential economic contributions of the forestry sector will not be realized.

Some have argued that it is undesirable to use wood for fuel because the multiplier effects of producing timber products will not be realized. This argument is somewhat fallacious. The argument is based on the belief that by using timber for products, each succeeding step from harvesting to delivery results in a "value added." However, it can be successfully argued that burning wood may provide even greater multiplier effects in that monies saved from burning wood can then be used to purchase goods and services (with their commensurate multiplier effects) which would not otherwise be possible. In addition, there is a value added

between purchasing stumpage, processing it into firewood (the price of a cord of wood less stumpage costs), and commensurate economic multipliers.

Stumpage price reflects the discounted value of converting the raw resource into a wood product and the subsequent sale (gross returns) of that product. Thus, the stumpage price also reflects the future value of the standing resource. If a greater stumpage price is gained by selling to fuelwood rather than timber product use, the multiplier argument becomes moot.

The summary and annotations found in this report delineate much of the relevant literature dealing with wood and energy. However, there is little economic data relating to (1) residential burning of wood with potential consumer savings, (2) the regional impacts of substituting wood energy for imported energy, and (3) the impact of increased fuelwood production on the forest resource base as well as on the other forest-using industries. Industrial applications of fuelwood use have been studied more rigorously, especially with regard to the utilization of wood residues from pulp, paper, lumber and wood fabrication establishments.

Whether increased use of wood energy becomes a part of the longrun solution in meeting rising energy demand depends upon such factors as:

- future availability of fuelwood supplies from round timber and mill and logging residues;
- economic characteristics relating to collection, processing and transportation of fuelwood;
- price relationships between fuelwood and alternative energy sources.

Additional research is necessary regarding:

1. What will be the impact on New England's wood-using industries and on the forest resource from increased burning of fuelwood?

2. What are the longrun demand and supply relationships of wood energy?

3. What is the advantage of encouraging domestic fuelwood use, which could result in millions of point sources of pollution? Why not focus solely on commercial conversion to wood energy?

4. What will be the effect of revised timber resource allocations for and development of a fuelwood industry on a) employment and b) income in traditional forest-based industries?

5. What is the optimum allowable harvest volume per year per State that would meet the objectives of the Multiple Use and Sustained Yield Act of 1960?

6. As cull volumes decline because of the applied TSIs and result in improving the quality and quantity of sawtimber yields, to what extent will fuelwood markets begin to compete with other forest-based industries for wood supplies?

7. What will be the longrun impacts on land use if the trend for wood energy continues?

8. What long-term effects will whole-tree harvesting have on the nutrient budget of the forests?

9. How much timber will be (and should be) harvested from public lands and used for fuel?

ANNOTATED BIBLIOGRAPHY

NOTE: Denoted annotations (+) were taken from an unpublished bibilography prepared as part of the *Initial Report on the Land and Water Conservation Program of the U.S. Department of Agriculture* by the Initial Report Team for the Land and Water Conservation Task Force. Numbers in parentheses refer to the literature citation number listed in the references section.

(*2*) Arola, Rodger A. "Logging Residue: Fuel, Fiber, or Both?: *ASAE Trans.* Vol. 18, no. 6, pp. 1,027-1,031. November/December 1975. (Paper no. 74-1550, 1974).

Wood residues in significant demand are those from manufacturing, not from logging. The pulp industry gets 31 percent of its total input from manufacturing residues and 4 percent from logging residues. Forest residues can cost 10 times as much as mill residues due to additional collection, processing, and transporting costs. If its fuel value will not cover the expense, then the high cost of collecting and transporting logging residues must be justified through upgrading them for fiber purposes. Technological innovation has only perhaps recently devised a cheap way to upgrade the logging residues so that wood fiber-using industries find them desirable. A new system debarks whole trees and chipped forest residues of up to 90 percent of their bark content at a cost of $5 per ton. Clean chips can go into pulp and paper manufacturing; bark chips can become fuel. Though the initial capital investment required for wood-burning plants might be double the cost of comparable units for oil and gas, the wood-fired system can usually repay its investors in 4 to 8 years out of fuel savings and other benefits.

The amount of forest residue discussed is the 9.6 billion cubic feet (gross volume) generated in the United States each year. Only about 6 billion cubic feet are believed recoverable. Six billion cubic feet have a gross energy content of 1,700 trillion Btus, but at an assumed boiler efficiency of 65 percent, 1,100 trillion Btus are available. Such a supply could have provided much of the 2,000-plus trillion Btus used in paper and board manufacturing in 1972. It is expected that residue material will be used increasingly for both fiber and fuel.

(6) Beardsley, William H. "Wood as a Source of Energy: A Forester's Gordian Knot," *Northern Logger and Timber Processor.* Vol. 24, no. 2, pp. 8-9, 31, 1975.

This article uses the analogy of an ecological chess game for determining the impact of wood fuel. Player A is the landowner and player B the harvester, with the forests as the chess board and the uses of the forests—timber production, wildlife habitat, aquifer recharge, wilderness, recreation, and pulp production—the playing pieces. There also is a newly introduced piece, a technological one—the $25 million 50 MW power plant which would consume 400,000 tons or 170,000 cords of wood chips per year for 30 years. This is, economically speaking, the smallest plant apt to be built due to the economies of scale and the difficulty in obtaining over 800,000 tons of wood per year reasonably close to any one plant. In the game simulation, the impact of utilizing wood for energy will show up in "the multiplicity of implications that such a use of wood would (have) on every other aspect of forest management policy," meaning on every other playing piece and on the board. Some outcomes can be expected: the landowner receives income from any of a number of wood markets for timber, including poor quality wood if sold for fuel; he can improve his stand, and if a hunter, make his stand more habitable for animals to his direct advantage; the harvester can market every portion of his tree and justify the costs of cull and residue removal by selling to manufacturing and new fuelwood markets; the paper companies could increase their wood supplies through full-tree harvesting—this increased supply could dissuade their fears of production cutbacks and wood supply shortages while also introducing considerable savings in fuel bills.

Replacing oil with indigenous fuel has substantial effects on the economics multiplier. However, care must be taken not to undercut the existing forest industry. A fuelwood industry could not compete with the jobs and income generated in pulp, paper, and logging industries.

(7) Beardsley, William and Kevin St. George. "Convert Forest Cull into Energy, and Optimize Forest Resourses," *Pulp and Paper Canada.* Vol. 78, no. 3, pp. 51-52, 54-55. 1977.

This article reviews the formation of the young cull wood market of today, attributing its recent development to two events: the invention of the whole tree chipper, and the increase in fuel and power costs. Using this low-quality material for fuel is not unpopular anymore; in the last decade, 250 wood-fired boilers were sold for industrial use. Cull wood sold in Vermont for

$29.50 per delivered cord in 1975; $21 for harvesting; $1 for stumpage; $4 for chipping; and $3.50 for transporting.

Mr. St. George uses his employer's paper company plant as a case in point to discuss utilizing whole tree chips for fuel and fiber. The pros and cons of a shifting harvest operation to whole tree chipping and the subsequent capital investments, added and lost incomes, and changes in labor requirements are analyzed. A green cord of residue has an energy content equal to that found in 2.3 barrels of Canada's bunder C fuel oil which is used by the plant to generate steam. By going to whole tree chips, 112,500 cords equivalent would be residue (due to low chip quality) which could displace 258,750 barrels of fuel oil, or at $9 per barrel, an initial displacement of $2.3 million. In addition, by going to whole tree chips, necessary harvestable acreage required to supply pulp would decrease by 3,200 acres. St. George also pointed out that labor requirements would decline by 450 persons (a plus in terms of company costs, a minus in terms of the Newfoundland employment rate). Although there are a number of problems in converting from roundwood to chip harvesting, it appears that there are definite cost-saving advantages.

(*8*) Bedrosian, Paul H. "Fuelwood and Its Environmental Considerations," *Proceedings from Wood Heating Seminar II of the Wood Energy Institute.* Pp. 12-28. 1977.

As wood gains distinction as a source of power, environmental damage becomes more likely. Vermont residents prove their seriousness about using wood for fuel; domestic firewood consumption for primary heating systems spread from 1 percent of all households in 1970 to 6.7 percent in 1976, with over 50 percent of all residences supplementing their heating systems with wood.

Terrestrial and aquatic pollution (from sediment and disturbance of wildlife habitats and watersheds) may become the aftershocks of inadequately controlled harvesting operations. Burning wood could pollute the air. EPA regularly checks for six air pollutants for compliance with National Air Quality Standards. Any of their levels could be aggravated by wood burning, though particulate matter and photochemical oxidants are the two most apt to worsen of the six. Home wood burners are more inefficient than industrial types; hence, they create oxidants. Industrial burners are more desirable because they are more precisely designed and regulated by law. Because homes using firewood could evolve into countless point sources of varying pollution levels, the

EPA is now in the process of writing the first emissions standards directly related to wood use. Air pollution from fuelwood consumption becomes more problematic if the emissions encounter particular local meteorological conditions that form and distribute the polluting molecules.

New England forests can supply 1,332 mcf of timber. This can supply a potential energy value worth 4,900 MW of electric capacity to the region, using assumptions given here. Ninety-eight wood-fuel power plants (50-MW capacity) can be supported on the New England timber. It is estimated that each plant will need 10,000 forested acres per year for its fuel supply or a total of 980,000 acres.

(*9*) Birkeland, Jorgen. "Conservation Research and Technology Role in Wood Burning," *Proceedings for Wood Heating Seminar II of the Wood Energy Institute.* Pp. 1-11. 1977.

This presentation addresses the Energy Research and Development Administration's (ERDA) program to establish the importance of wood as an energy source, a program which could partially fulfill a broader ERDA objective—to produce three Qs for annual consumption in the United States by the year 2000 solely from today's waste matter. Within ERDA (now part of the U.S Department of Energy) the Division of Conservation Research and Technology (CONRT) conducts technological research to improve energy conversion devices for multifuel usage. The Combustion and Fuels Technology (CFT) Branch of CONRT investigates the processing of nonpetroleum based alternative fuels into heat, and its technological requirements.

Two kinds of alternative fuels are identified: primary alternative fuels (PAFs) such as coal and shale, and secondary alternative fuels (SAFs) like biomass residues, municipal and industrial waste, and related fuels. Wood and SAF have again become popular, especially in New England. The cold winter of 1977 saw burner installations multiply dramatically, adding 100,000 burner units to one firm's sales sheet alone. If developed skillfully, fuelwood may eventually generate 1.3 Qs per year nationwide (more than one-third of the overall set by ERDA) in lieu of using oil and gas reserves.

New England, the initial target area, could locally support a new \$3 to \$4 billion industry on its waste wood and could produce an estimated 0.4 Qs per year to compete with 1977 prices of energy produced from oil, according to ERDA.

Specifications, codes, standards, handbooks, and legislative support are all built into this comprehensive

project in addition to special studies on fireboxes, systems, economics, and technologies.

Economic studies will emphasize the New England region and intend:

1. To define the cost effectiveness of fuelwood systems as replacement for existing prime fuel systems.
2. To obtain pricing data for locally delivered wood to determine possible need for price supports.
3. To provide cost-benefit analysis on the sociological effects of the combustion of fuelwood rather than options (for example, production of methanol or pipeline grade gas).

Most published results of ERDA's program are not due until 1982, and no publications are cited for systematic and economic analyses.

(*15*) Bones, James T. "Residues for Energy in New England," *Northern Logger and Timber Processor.* Vol. 25, no. 12, pp. 20-22, 34. 1977.

New England's energy situation, its annual fuel consumption and the amount of energy that timber supplies could potentially provide are discussed. The 2.8 Qs consumed by New England in 1971 is just more than one-third of the projected 7.5 Qs that the region is expected to use in 1985. To meet its needs for power, the six-State area used a combined 12.6 mcf of its manufacturing residues or 0.2 million ODTs for fuel in 1973. The proportions of recovered mill residues were high for the area, ranging from 77 percent for Massachusetts to 86 percent for Connecticut and Rhode Island.

Massachusetts, which used the smallest percentage of mill residues, also had the most forest land acreage cleared in 1973 (27,000 out of a total 77,000 acres cleared in New England). This wood could have become fuel. Above-ground biomass, in volumes of 2,045,000 ODTs of wood and 300,000 ODTs of bark was also available.

In short, 8.5 million tons of residues are presently available in New England, with a gross energy content to 150 trillion Btus and a net value of approximately 80 trillion Btus. Three percent of New England's energy needs in 1971 could have been met by this energy reserve.

(*19*) Brooks, David J. and David B. Field. *Potentials of Charcoal Production for Forest Stand Improvement and Domestic Space Heating in Maine.* Coop. For. Res. Unit, Res. Bull. no. 1, Univ. of Maine, Orono. March 1979.

Conclusions reached in this report suggest that if

charcoal could capture approximately 16 percent of Maine's total domestic space-heating market, then half of the State's standing volume of low-grade hardwood could potentially be used in 20 years. The thesis is that charcoal production and marketing could pay for the TSI practices necessary to significantly improve the present low quality of hardwood stands. Although the authors point out that nearly half the heat energy value of wood is lost through the conversion process, such a loss would only be real if there were an opportunity for marketing the solid wood directly. The authors believe that charcoal manufacturing should be undertaken only in those areas so remote that transportation costs would preclude the marketing of solid wood, at least to the extent that the convenience of charcoal would be sufficient to offset any remaining differences.

The comprehensive report includes estimates of raw product sources, volumes, and weights. An analysis of both the demand and supply characteristics as well as marketing considerations is also included.

(*21*) Bureau of Land Management. "Chipharvester Ideal for Slash Cleanup," *W. Conserv. J.* Vol. 31, no. 3, pp. 32-33. 1974.

Demand for chips is escalating in the United States and abroad, requiring that more raw material sources be found to chip and sell for at least the current price of $50 per unit. Morbark's total (wholetree) chipharvester makes it possible for one person to handle and chip whole trees up to 21 inches in diameter in under 1 minute and fill a 25-ton truck in 15 to 20 minutes. Five to seven crew members can turn out 250 to 300 green tons of chips per day. Chipping volumes as high as 450 tons per day are reported by some east coast firms. The machines have fully penetrated that region and are only sparsely scattered throughout the west coast. Fiber yields have commonly been doubled by these chippers in comparison with conventional havesting operations.

+(*23*) Burns, James W. "Some Effects of Logging and Associated Road Construction on Northern California Streams," *Amer. Fisheries Soc. Trans.* Vol. 101, no. 1, pp. 1-17. 1972.

Effects of logging and associated road construction on four Northern California streams were not detrimental to anadromous fish production when adequate attention was given to stream protection and channel clearance. However, extensive use of bulldozers on steep slopes and in stream channels caused excessive erosion and sedimentation. Carrying capacities for juvenile salmoids were reduced when high temperatures, low dissolved oxygen

concentration, and adverse sedimentation accompanied logging.

(*29*) Corder, Stanley E. "Wood-Bark Residue is Source of Plant Energy," *For. Industries.* Pp. 72-73. February 1974.

On the average, less than half the log entering a mill becomes a primary product; the rest becomes residue. This article provides conversion tables for estimating the type and volume of residues generated in processing. Coarse residues comprise the largest class of residues from manufactured lumber. Undried veneer represents the greatest component of plywood residues.

Wood's heat values change according to the physical properties, averaging 8,000 to 8,500 Btus per dry pound for resin-free wood (mostly hardwoods); nearly 9,000 Btus per dry pound for resinous woods (mostly softwoods); and a high of 9,000 to 10,000 Btus per dry pound for softwood bark (lower for hardwood bark).

(*30*) Curtis, A. B. Jr. "The Energy Problem: How to Calculate Wood Fuel Values," *For. Industries.* Vol. 103, no. 13, pp. 44-45. 1976.

Specific formulas should be used to calculate the moisture content, green and dry weights, and ultimately the net usable heat in residue wood rather than accepting broad generalizations made about these characteristics. The energy content in Btus of different wood fuel stoves should be estimated for each specific stove of wood because of the great variances in boiler and combustion efficiencies, densities, and greenness of wood. Certain professions disagree as to the correct equation for determining moisture content; therefore, standardized rules are needed to avoid discrepancies in calculations. Boiler company engineers use: MC* = (green weight minus ovendry weight)/(green weight) x 100/1. The fuel value of a pound of residue is calculated using the weights of wood and water in the residue. The formula recommended by Brown, Panshin, and Forsaith in the *Textbook of Wood Technology* (1952) is:

$$\frac{\text{Green weight}}{\frac{1\text{-MC*}}{100}} = \text{dry weight}$$

It is recommended that the energy value in the net usable heat be further reduced by 5 percent to account for other ignored losses. An estimate of 5,840 Btus per pound of planer shavings at 15-percent moisture content and 78-percent boiler efficiency resulted from these

equations. For differing boiler efficiency levels, adjustments are possible to reevaluate new energy values.

(*31*) Dalton, M. M., O. B. Durgin, J. H. Herrington, and R. A. Andrews. *Household Fuel Wood Use and Procurement in New Hampshire.* Agr. Exp. Sta., Univ. of N.H., Durham, Res. Rep. no. 59. October 1977.

This report is the result of a telephone survey of private homeowners in New Hampshire to determine fuelwood use, source, procurement, and price paid for the winter of 1976-77. Nearly 1,200 households were contacted, of which 52 percent burned wood. Sixty-nine percent of the wood-burning households cut all or part of their own fuel wood. The sample household wood-use figures were expanded to arrive at a statewide use of 300,000 cords per year, 200,000 cords of which are cut by household members and 100,000 cords of which are purchased. Only one-fourth purchased their entire supply. Ninety-seven percent of the wood users burn it in a stove, fireplace, or both, and a few use wood-burning furnaces. The fall months were the chief periods to buy fuelwood, which ranged in price between $26 and $50 per cord. Some exceptions developed on both ends of the price spread. Of the 254 households which purchased their wood, 68 percent bought 2 cords or less, 16 percent bought 2 to 4 cords, and 16 percent purchased more than 4 cords. The cutoff point between fireplace and small stove use for supplemental heating and wood as a major source of heat is around 4 cords annual consumption. Ten percent of the households had trouble obtaining wood. The total dollar value of wood purchased was $4 million. For a perspective on what the 300,000-cord consumption level means, the Brown Pulp and Paper Company consumes 400,000 to 450,000 cords of pulpwood per year. One conclusion of the study, not supported by any trend analysis data, is that there is apparently no indication of a major shift to fuelwood as a primary source of heating fuel.

(*32*) Dost, William A. "Comparative Cost Study Made on Steam Production Costs on Oil and Wood Fuel Compared by Discounted Cash Flow Method," *For. Industries.* Vol. 95, no. 2, pp. 90-93. February 1968.

Satisfactory automated wood-fired boilers for low pressure steam production are available. These units are characterized by relatively high initial cost and low operating costs, exactly the reverse of oil- and gas-fired units. In this study, the total costs of oil and wood fuel are compared by the discounted cash flow method. assuming no value is attached to the wood fuel. Using this

method, the wood-fired unit was found to be the better investment at the location considered.

+(*33*) Douglass, James E. "Watershed Values: Important in Land Use Planning on Southern Forests," *J. of For.* Vol. 72, no. 10, pp. 617-621. 1974.

Although water quality is the most pressing problem in the South, quantity of water from forest land is also important in land use planning. Management of hardwoods for sustained yield can increase water supplies by 0.5 to 2 acre-inches annually. Conversely, anticipated conversion from hardwood to pine in the South could reduce available water supplies. Protection or improvement of hydrologic performance of forest soils will become an important element of forest land use planning.

(*35*) Ellis, Thomas H. "Should Wood Be a Source of Commercial Power?" *For. Products J.* Vol. 25, no. 10, pp. 13-16. 1975.

Ten percent of the fuel requirements of U.S. steam-electric generating plants could have been satisfied by the estimated unused mill and logging residues in 1970 measuring at least 4 inches in diameter. However, coal priced at 70 cents per million Btus (mid-1974 prices) would probably still have been cheaper to use than wood residues. Residues are not expected to be available for major fuel purposes in the future because of the increased demand for processing them as onsite fuel and reconstituted products at forest products plants. The costs a firm could be spared in disposing of remaining waste wood are not discussed.

Adhering to Forest Service supply estimates, Ellis concludes that if all waste—mill and logging residues, tops, branches, and all nongrowing stock material at or larger than 4 inches in diameter—had been collected, a maximum of 7 percent of the U.S. fuel requirements for steam electric facilities might have been supplied. The energy values of roots, stumps, and material under 4 inches in diameter are only incidentally recognized. There would still be an economic advantage to using coal unless all costs for collection, transportation, and processing of residues averaged less than $3.60 per ton. Chipped wood costs rose with but not because of fuel price increases; demand for the chips and manufacturing residues was increased by pulp producers. Ellis found it highly unlikely that fuel plantations, where crops are grown for their fuel values, would occur because of the extensive acreage requirements and expenses involved.

(*40*) Foulds, Raymond T. Jr. *Wood as a Home Fuel.* Ext. Serv., Univ. of Vt., NE-7. February 1976.

At 20-percent moisture content, the weight per cord of wood can range from over 2 tons (for denser hardwoods) to approximately 1 ton (for lighter softwoods). Greenwood adds 800 to 1,400 pounds per cord.

The more valuable commercial species of wood such as yellow birch, black cherry, white ash, sugar maple, red oak, white oak, basswood, tulip poplar, white pine, and red spruce should be avoided as fuel, since none of these have a high heat content. The four species with the greatest heat value per standard cord (of 32 species listed) are shagbark hickory, black locust, ironwood, and apple.

+(*41*) Fredriksen, R. L. *Impact of Forest Management on Stream Water Quality in Western Oregon.* 26th annual meeting, Pollution Abatement and Control Committee of the For. Products Res. Soc. Dallas, Tex. June 18-23, 1972.

Water quality of forest streams in Western Oregon can be markedly influenced by the type of forest management. In the H. J. Andrews Experimental Forest, landslides larger than 100 cubic yeards increased dramatically on slopes greater than 40 percent. In two separate studies, roads and especially road failures drastically increased suspended sediment concentrations. Clearcutting and slash burning produced considerably less sediment than roads. Highest concentrations of native nutrients appeared in streams after slash burning on clearcut watersheds. Nutrient outflow declined with revegetation. Such studies can demonstrate to managers certain activities and practices which must be done with greatest care in order to avoid pollution of streams.

(*43*) Gay, Larry. *The Complete Book of Heating With Wood.* Charlotte, Va. Garden Way Publishing. 1974.

Half of the United States could be provided with year-round heat from domestic wood supplies without depleting forests. This estimate is based on an assumed consumption of 5 cords per year for the average American home. Half of wood's fuel value is in volatile gases that are given off when the wood gets hot. Thus, efficient wood burning involves the burning of potentially combustible gases. After subtracting losses from harvest and mortality, the Eastern United States' annual net growth is 61 million cords of hardwood and 36 million cords of softwood.

(*46*) Hokanson, A. E. and Raphael Katzen. *Chemicals from Wood Waste.* Cincinnati, Ohio, Raphael Katzen Associates. 1975.

This article discusses the extraction of methanol, ethanol, furfural, and phenolics from residual wood supplies. Hardwood residues are the feedstock for most of these processes. Since most of the United States' hardwoods (82 percent) are in the Midwestern or Eastern States, the chemical plants would locate there also. Wood requirements would run 760 ODTs per day at a plant which would produce 40 million pounds of furfural per year. Investment and operating costs are projected for chemical manufacturing using $34 per ODT of waste wood as an input cost. Currently, it is economically infeasible to produce any of these chemicals from wood residues.

+(*47*) Hornbeck, James W. "Streamflow Response to Forest Cutting and Revegetation," *Water Resources Bull.* Vol. 11, no. 6, pp. 1,257-1,260. 1975.

Clearing forest land interrupts the hydrologic balance. Experimental cuttings on two hardwood forested watersheds in New England increased annual streamflow as much as 41 percent. Most of the increase occurred in summer and early autumn when additional streamflow was most needed. Within 4 years after complete forest clearing, revegetation helped to almost diminish the annual streamflow increases. Rotation cuttings will be necessary to maintain the increased volumes of water over time.

+(*48*) Hornbeck, J. W. and others. "Moderating the Impact of Contemporary Forest Cutting on Hydrologic and Nutrient Cycles," *Publication No. 117 de l'Association Internationale des Sciences Hydrologiques Symposium de Tokyo.* Pp. 423-433. December 1975.

Two contemporary forest practices, block clearcutting and progressive stripcutting, are being studied on small watersheds at the Hubbard Brook Experimental Forest in New Hampshire to determine their impacts on the water yield and nutrient ion concentrations of streams. Block clearcutting is a complete harvest of all trees in one single operation; progressive stripcutting also involves harvesting all trees, but by periodic cutting of adjoining strips over several years. For the first 2-year cycle of stripcutting, in which one-third of the watershed was cutover, annual streamflow increased approximately one-tenth of the estimated increase that would have occurred if the watershed had been completely cut. During the second cycle, in which an additional third of the watershed was cut, the annual increase was 114 mm, or 35 percent of the total that would have been expected if the watershed had been completely cut. Nutrient ions in the streams were also affected. For the first 4 years of

the stripcut harvest, stream water concentrations increased by more than 7 mg/l for nitrate, 0.9 mg/l for calcium, and 0.3 mg/l for potassium. Sulfate concentrations declined by as much as 1.5 mg/l. In contrast, block clearcutting caused maximum increases of 23 mg/l for nitrate, 1 mg/l for calcium, and 1 mg/l for potassium, and an apparent decrease of 2 mg/l for sulfate. The smaller than anticipated water yield increases and the lower ion concentrations after stripcutting indicate that the impact of a complete tree harvest can be moderated by changing the time span and configuration of the cutting.

(*49*) Houghton, John E. and Leonard R. Johnson. "Wood for Energy," *For. Products J.* Vol. 26, no. 4, pp. 15-18. 1976.

Waste wood can only fill between one-tenth and four-tenths of 1 percent of this country's energy needs, assuming that the wood is transformed to alcohol. Wood fuel in the form of liquid alcohol as opposed to direct burning of wood is this article's main theme. Physical accessibility to waste wood is not so much the concern; the crux of the energy question is its economic accessibility. As scarcities of energy sources increase, wood will become more economically accessible and use priorities of wood will be realigned. U.S. authorities predict that forest products demands will rise by 50 to 100 percent by the year 2000 and foresee serious competition for wood fiber in the not too distant future. It is only feasible, therefore, to use wood as a supple power source for small localities with low energy needs and large supplies of waste wood. The strength and power of the market system, the price functions of substitutes, and purchase prices of fuels are the primary emphasis used to determine the practicalities of wood fuel.

(*50*) "How Wood Residues Can Help National Energy Needs," *Wood and Wood Products* in cooperation with T. H. Ellis. Pp. 52-53. April 1976.

Forty percent more softwood fiber and 100 percent more hardwood fiber may be attained from the Nation's forests if the above-ground components of cull, dead, small diameter and weed trees are harvested. Because few States have data on residues from their nongrowing stock timber, accurate estimates of regional and national residue supply are difficult to make. Increasing the use of chip harvesters and harvesting the complete tree could yield substantially more residue. Sizeable reductions in future logging residue volumes are anticipated as overall demand for residue increases. The high cost of collection

and transport are the major obstacles to more complete logging residue use.

(*52*) Johnson, Leonard R. and Jim Arkills. "Integration of Whole Tree Chipping with a Traditional Sawlog Operation," *ASAE Trans.* Vol. 19, pp. 802-806. September 1976.

This article looks at the economic feasibility of using a whole tree chipper in strictly sawlog harvest operations. Sawtimber by definition is not chipped but taken in log form. Thus, it must be determined whether the cull and dead trees and the nonsalable portions of sawlogs can justify the costs of their being chipped and removed from various harvest sites and topographical conditions. That determination depends on the availability of natural landings on which to place the chipper and loader. In sequential operations, a site is cleared of its sawtimber first, then the chipper enters the clearing to process the remaining slash and cull. In simultaneous operations, both harvesting and chipping machinery can operate on the same site concurrently because there is enough space available.

Some problems relate to the roads used by trucks hauling the chips. These roads were designed for long log trucks with swivel bunks and other differentiations. Some modification of road grades and curve radii may be necessary at an additional expense, a factor which could single-handedly make residue and cull removal uneconomical. Data indicates that sequential operations usually will prove cheaper than simultaneous ones. What must be noted is that for every pile of residue that gets chipped there will be more delay to sawlog productions. Since sawlogs carry the highest returns, it is likely that much of the residues will remain in the forest unchipped and unrecovered until the market price compensates for their extraction.

(*53*) Johnson, Leonard R. and Cleveland J. Biller. "Wood Chipping and a Balanced Logging System Simulation Can Check the Combinations," *ASAE Trans.* Vol. 17, no. 4, pp. 651-655. 1974.

Three different model simulation runs for a 25-acre clearcut were conducted to determine the best combination of harvesting machinery (chipper, skidders, vans, hauling trucks, and fellers) for an experimental forest site. Results were from simulation of the *S*imulation *A*pplied to *Lo*gging *S*ystems model (SAPLOS) on time and motion studies of a Morbark Model 75 Total Chip Harvester. The cost data here allowed for a chipper life of 8 years and an original cost of $91,000. Twelve

different combinations of equipment were simulated, the least expensive of which was a method harvesting the 79,600 cubic feet in 12 days at a total cost of $8,890. The models were only intended to provide a means of selecting the least cost harvest technique for a particular site, while maximizing the amount removed from the woods.

(*54*) Johnson, Robert C. "Some Aspects of Wood Waste Preparation for Use as a Fuel," *TAPPI.* Vol. 58, no. 7, pp. 102-106. 1975.

The effect of fuel moisture on recoverable wood heat is seen in the case of a lumber company which was able to increase its steam output by nearly 200 percent from 66,000 pounds per hour to 112,200 pounds per hour by using dry instead of wet wood fuel. Combustion zone temperature is a function of the fuel's moisture; the more moisture there is in the wood, the less hot the combustion zone will become. The hotter the combustion zone temperature, the faster the rate of burning and the more complete the combustion. Thus, it can be economical and less harmful to the environment to prepare hogged fuel for burning by predrying it and removing dirt. This paper also looks at the performance of numerous methods for drying and burning residue fuels according to their moisture content, fuel type, feed rates, and steam outputs.

(*59*) Kingsley, Neal P. *The Forest-Land Owners of Southern New England.* USDA For. Serv. Res. Bull., NE-41. 1976.

A 1972 survey characterizes the forest land owners of Southern New England (Connecticut, Massachusetts, Rhode Island) as follows: 184,100 ownership units hold the commercial forest land in the three States, and 88 percent of the units are in individual holdings and account for 78 percent of the commercial forest land acreage. Most owners own the land for reasons not related to monetary or material gains, and few have definite intentions to harvest. Estimates of prospective timber availability from private lands are limited in time, and are very sensitive to outside factors, but between 50 and 90 million cubic feet are expected to be offered for harvest each year in New England by private owners. Forty-eight percent of the land that was harvested by the present owners was cut because it was either mature or the owners were employing other management practices (26 percent and 22 percent of the harvested acreage, respectively). Sixty-nine percent of Southern New England's private commercial forest land has not been

cut by present owners, mainly for fear of scenic destruction. Owners need to be made aware that forestry programs can be designed to meet many owner objectives. The forest land base is shrinking and the demand for wood can be expected to increase worldwide.

(*61*) Kingsley, Neal P. *The Timber Resources of Southern New England.* USDA For. Ser. Res. Bull., NE-36. 1974.

The Southern New England States (Connecticut, Massachusetts, and Rhode Island) have vast forest lands that cover nearly 60 percent of the total land area in those States. Growing stock volumes have increased 60 percent over their 1953 volumes, despite an 11-percent drop in commercial forest land acreage. The average net growth-to-removal ratio for timber in 1972 was more than 4 to 1. Of the removals, 85 percent resulted from changes in land uses, and less than half were utilized. Continued low removal figures may have a negative impact on the region's future forests and environment. The current low harvest volumes are having adverse effects on the volumes of quality sawlogs, in addition to changing the species characteristics of the stands toward more shade-tolerant tree types.

Forests are desirable for maintaining stable streams; they are noted for their low levels of stream sedimentation compared to other types of land use. However, New England lost an average of 35,000 acres per year of its commercial forest land during 1953-72. It is believed that this rate will decline by 1,000 acres annually (34,000 acres in 1973, 33,000 in 1974). Because of the annual losses of timberland and many legal knots, there is substantial importation of wood fiber from outside the region.

(*66*) Lloyd, Sam. (Rep.). *Governor's Task Force on Wood as a Source of Energy: State of Vermont, 1975.* Task Force Chairman, State of Vermont, House of Representatives. 1975.

A large-scale wood energy industry could provide up to 25 percent of Vermont's power. Commercial forest land covers 75 percent of the State land area, 90 percent of which is privately owned. Total growing stock volumes equal 4.7 billion cubic feet (averaging 1,068 cubic feet, almost 13.4 cords, or 19.8 air-dried tons of merchantable material per acre). More than 40 percent of an entire harvested tree is left in the forest after normal logging operations. Based on this percentage, the estimated weight of growing stock volumes (minus roots) is

more nearly 33 air-dried tons per acre, with rough and rotten volumes around 6 air-dried tons (265 cubic feet per acre). Presently, Vermont's timber growth-to-removal figures are at most 3 to 1. Over 36 percent of all softwoods and 54 percent of all hardwoods (measuring no less than 1 inch in diameter) are in the rough and rotten category. If a market developed for poor quality wood, harvests could be quadrupled without adversely affecting the environment. Vermont's average net growth could be increased to at least three times its current rate through removing poor, undesirable trees.

Only 16 percent of the total volume of all residues was not being used in 1972. Paper mills seriously compete with fuelwood markets for mills residues. Cost data are presented for firewood harvest and transport operations.

Comparative costs per million Btus for different energy sources are charted according to 1975 energy prices, assuming conversion efficiencies for wood between 60 and 65 percent. Based on these prices, roundwood (mixed hardwoods unsplit, undelivered) was the least expensive energy source ($1.68 per million Btus) and residential electricity generation was the most expensive ($10.62 per million Btus). This study assumes average consumption of 10 to 20 cords of wood per household per year in wood stoves, which is a very high estimate. Converting homes to wood heat would run from $2,000 to $3,500. The 20 trillion Btus used in Vermont annually could be replaced by 1 million cords of wood (1.32 million total cords are currently generated each year).

A well-documented environmental impact assessment on wood harvesting and burning is included. The most fundamental threat to environmental well-being is extensive utilization and removal of whole trees, which should be strictly controlled to prevent losses of nutrients and soil.

It was anticipated that a wood fuel venture would generate $44 million in gross revenues and add 2,000 jobs. An economic multiplier of 12 to 1 was estimated for a fuelwood market where 50 percent would go into related equipment (6 to 1 remaining as the direct economic multiplier). But due to the escalating forest land tax assessments, it is uncertain whether added timber yields and revenues will compensate for the income loss in foregoing other ventures.

(68) Mann, Stephanie. "Wood Burning May Lift Insurance Rates," *The Washington Post.* Page E-4. Saturday, November 19, 1977.

Homeowners' insurance rates are bound to go up because of the increase in fire losses and the suspicion that wood burners are to blame. Code standards are now being written specifically for wood heaters. Reliable statistics on actual fire losses caused by wood stoves are not available; officials have only just begun collecting data.

+(75) Megaham, W. F. and W. J. Kidd. *Effect of Logging Roads on Sediment Production Rates in Idaho Ratholith.* USDA For. Serv. Res. Pap. INT-123. 1972.

An analysis of sediment yields following road construction suggests that the largest proportion of sediment is produced the first year following construction. Sediment yields decrease rapidly with time to a minimum level within 3 or 4 years, which indicates that stabilization measures must be installed immediately after construction. Revegetation measures should be coupled with some procedure for providing mechanical stabilization during the period that vegetation is being established.

(76) Miller, W. L. and H. W. Everett. "The Economic Impact of Controlling Nonpoint Pollution in Hardwood Forestland," *Amer. J. of Agr. Econ.* Pp. 576-583. November 1975.

An input-output analysis is used to develop economic impact data for alternative methods of controlling sediment loss in forests—the single major source of pollution in these areas. This analysis examines the indirect costs incurred because control of nonpoint pollution is achieved indirectly through changing land use and land management practices. The total regional change in income is argued to be a more appropriate measure of economic impact than direct income change because controls remove some lands from production and/or cut the productivity of other lands. This idles land resources and directly forces society to forfeit some output.

Applying different rates of harvest and discount, the most profitable of several harvest scenarios are described. The cost of nonpoint pollution control is greatly underestimated. Regional income changes from reduced sediment loss are approximately 23 times greater than direct income changes and therefore must be used to determine the economic impact of such pollution controls.

(77) Morey, Jerry. "Conservation and Economic Harvesting of Wood Fiber by Using Whole Tree," *TAPPI* (Technical Association of the Pulp and Paper Industry). Vol. 58, no. 5, pp. 94-97. 1975.

Ninety pulp mills now use whole tree chips, and statistics prove the feasibility of such use. Whole tree

utilization provides two significant improvements: twice as high a fiber yield is realized, since previously unmerchantable stands are harvested and raw material costs are drastically lowered. Whole tree chips can be delivered to the mill at $6.22 per ton, compared to $20 to $30 per ton with conventional harvesting. Half the acreage is required, less labor is needed, and the land is immediately ready for replanting. Equipment needed includes a feller-buncher with a shear, grapple skidders, and a whole tree chipper. A six-person crew using this equipment can produce 280 tons of chips per day in one shift. The operation is very effective in pine thinning, selective cutting of hardwoods, and in cleaning up after logging operations.

(*79*) Morton, F. L. "In-House Generation of Electricity from Wood Waste Residue," *For. Products J.* Vol. 26, no. 9, pp. 73-76. 1976.

To be economically practical, wood waste should be burned to produce steam electricity only under special circumstances. The circumstances were favorable for one pulp mill to use its wood wastes. The mill needed a new boiler, incurred significant expenses transporting and disposing of refuse wood, and energy (steam) shortfalls occasionally occurred. Paper mills can also burn waste wood more effectively because they use noncondensing turbines.

Small generating units (10 MW) require more capital per MW output than larger units. However, installed turbo-generators can contribute significant steam loads for power generation; 37,000 added pounds per hour of steam was reported by a newsprint mill. Not only do turbo-generators utilize the heat more efficiently, which is more environmentally desirable, but having one can be instrumental in obtaining better power contracts with local utilities.

+(*80*) Myers, Clifford A. and Meredith J. Morris. "Watershed Management and Habitat Values in Coniferous Forests," *Proc. Symp. Mgmt. For. Range Habitats for Nongame Birds.* USDA For. Serv. Gen. Tech. Rep. WO-1. 1975.

Watershed management practices in coniferous forests can produce thinned stands, cleared openings, and new plantations. Clearcutting patches to increase water yields had the greatest potential for changing nongame bird habitats. Changes in the vegetative cover will increase habitat diversity, which is frequently but not always beneficial to birds.

(*81*) New England Energy Congress. *Final Report: A Blueprint*

for Energy Action. Executive Summary and Recommendations, the New England Energy Congress, Boston, p. 40. May 1979.

This report summarizes a great deal of energy research dealing with New England. The report details New England's energy position relative to U.S. averages with regard to regional dependence on petroleum; the amount of energy imported from both OPEC-controlled pricing lanes to non-OPEC pricing lanes; and policies to decrease dependence on foreign sources of energy, increase regional energy supplies, and increase conservation practices as well as recommendations for the various energy consuming sectors. The report is excellent and concise, and its detailed policy recommendations enumerate the social, economic, and institutional constraints likely to be encountered.

(*82*) New England Federal Regional Council. *New England Energy Situation and Alternatives for 1985.* Energy Resource Dev. Task Force, Energy Statistics and Projections Work Group. Updated August 1977.

New England relies too heavily on oil imports and a minimal development of native energy sources; consequently, energy prices are 45 percent higher there than the national average for electricity.

The New England Governors Energy Policy set a goal to decrease the region's oil dependence by 20 percent to where oil would fulfill 65 percent of the total regional energy demand by 1985. A maximum annual savings equivalent to 287 million barrels of oil might be achieved if several efforts were combined: conservation, the expansion of nuclear power, the developemnt of St. George's Bank's outer continental shelf, and broader use of coal and alternative energy sources. Oil equivalencies are important to realize because oil has a disproportionately large share of New England's energy consumption. In 1976, 57 percent of New England's electricity was produced from oil, though oil produced only 16 percent of the electricity for the United States. It is interesting to note that wood utilization is not given as a significant energy source in Connecticut, Rhode Island, or Massachusetts, but it displaces the largest oil equivalent (21.3 million barrels per year) of all the alternative energy sources considered.

In 1975, 2,781.6 trillion Btus were consumed by the region, of which only 15 trillion were produced from hydroelectric facilities. Fifty-two percent (1,455.7 trillion Btus) of the energy was lost in generation and transmission; 48 percent was available for final consumption.

Relevant energy legislation is summarized, focusing on

P.L. 93-159, P.L. 93-275, P.L. 93-913, P.L. 93-473, P.L. 94-163, and P.L. 94-385, which cope with energy shortages, development of energy supplies, and conservation.

The latter half of the report explains the origin of the task force and the creation of the Model Project Independence Evaluation System (PIES) as a forecasting tool for policy assessment. A base case with varying nuclear capacities and a high conservation case, with the absence of oil refineries, are presented. Model assumptions include the deregulation of natural gas prices, the eventual total decontrol of oil, and competitive domestic behavior. Forecast highlights include a decline in oil dependence by 1985 to 69 percent, with high conservation and substantial nuclear use. Though relative oil dependence declines, the model shows that total oil consumption increases. The region can save over $2 billion in end-user energy expenditures in 1985 through high conservation and use of nuclear power. Conservation actions account for over 90 percent of this savings.

(*83*) New England Federal Regional Council. *The Potential of Wood as an Energy Resource in New England.* Energy Resource Dev. Task Force, Wood Utilization Work Group. September 1977.

The New England forests are vast energy resources which should be utilized to lessen national dependence on foreign fuel. The sources, volumes, and combustibilities of different fuelwood species are treated in terms of economics and fuel potentials. This wood energy is significant enough to be developed into power. According to 1985 projections, over 21 million barrels of oil could be saved annually in New England through forest fuel utilization.

Although timber supply data is incomplete, some aspects of the region's forests are certain: red maple and hemlock are reaching pest proportions due to low demand; over 50 percent of Maine and New Hampshire forests are overstocked; the total wood resource in New England is estimated at 60 billion cubic feet, equal in energy to 18 quadrillion Btus, 700 million tons of coal, or 3 billion barrels of oil. Amounts of wood residues from mills and logging grossed a volume of 91, 364,000 cubic feet (excluding bark volumes) for the six-State area. In 1971, 3 mcf of logging residues were generated in Southern New England yet 60 million cubic feet of timber were cut in land-clearing operations that same year in those States. The latter material went primarily unused and is commonly not accounted for in the records of residue volumes.

Cost data points up the misconception that wood

availability depends on immediate proximity to supply. In an example used in this report, 60 tons of chips hauled 75 miles could be 12 percent more expensive per ton than 20 tons of chips hauled 50 miles, and still the overall prices for the two alternatives would be equal. Two alternative equipment combinations and their costs are provided for two harvest techniques: the clearcut and the selective harvest. Chips and pellets are given at the most efficient forms of wood fuel for nearly all types of burners. The increase in use and sales of domestic stoves and commercial/industrial boilers shows the serious attention that wood fuel is being given in the region and nationwide.

(*86*) Noyes, John H. *Wood for Fuel.* Ext. Serv., Univ. of Mass. December 1973.

This article recommends cutting trees which are crooked, dead, diseased, large crowned, or of low market value, especially in overstocked stands. Generally, all other trees should be saved. The potential safety hazards involved make it important for loggers to know fully about each tree they cut and machines they use. Safety rules on burning wood and technical assistance available from private and State foresters on growing, cutting, and burning wood for fuel are discussed.

Wood dries quickly in May and June, but may reabsorb moisture from summer rains. Seasoning time varies by species of wood and atmospheric conditions, but wood seasoned 1 year averages 100 percent of its fuel value. Standard cords measure 4 feet x 4 feet x 8 feet, average 128 cubic feet (gross volume), have 60 to 115 cubic feet of solid wood. Face or short cord measurements are not absolute; the width can be anything under 4 feet. The number of trees needed to equal 1 standard cord can be estimated if the diameter of the trees at breast height are known.

Fuel values for coal in tons, no. 2 fuel oil in gallons, and natural gas in 100 cubic feet are compared with the fuel value in one air-dried cord of 11 different tree species. A cord of dry hardwood of mixed species weighs approximately 2 tons and is equivalent in energy to a ton of coal or 160 to 170 gallons of fuel oil.

(*87*) Overend, Miles. "Beating Higher Fuel Costs," *Canadian For. Industries.* Vol. 95, no. 11, pp. 34-35. 1975.

Problems arose in British Columbia (B.C.) when lumber mills consulted the B.C. Forest Service about using waste wood for fuel. Until recently, when wood was seriously reconsidered as a fuel source, there was never an issue as to whether stumpage rates included

bark purchases with the wood. Now that bark has attained energy status, however, the B.C. Forest Service, in behalf of the Federal Government, may claim ownership of the bark and thus make additional charges for its harvest.

A dry kiln, converted to wood fuel, could pay for itself in less than 2 years. Commonly, 1,600 cubic feet of natural gas are consumed in drying 1,000 board feet of lumber, though 500 pounds of shavings could dry the same. The demands of labor and operating codes escalate expenses and require full-time trained operators and attendants at the burners. One system, the Thermex-Reactor Process of organic waste gasification, has great promise for producing fuel gas from various organic wastes and low capital and operational costs. This process will be less harmful to the environment than other burner processes of organic wastes.

+(*88*) Patric, James H. "River Flow Increases in Central New England After the Hurricane of 1938," *J of For.* Vol. 72, no. 1, pp. 21-25. 1974.

The New England hurricane of 1938 uprooted or broke off vast numbers of trees in watersheds of the Connecticut and Merrimack Rivers. Annual flow in both rivers increased about 5 inches during the first year after the hurricane. Another 5 inches of increased flow occurred at diminishing rates during the next 2 or 3 years. At least half of these flow increases occurred in July, August, and September when streams normally are at the lowest levels of the year. There was no evidence of increased flow 5 years after the hurricane when forest regrowth was well underway, nor any evidence that forest cutting, as presently practiced in the Eastern United States, has measurably increased the flow in larger streams.

(*94*) Raphael Katzen Associates. *Chemicals from Wood Waste.* USDA For. Serv., For. Products Lab., Madison, Wisc. December 24, 1975.

This study investigates the manufacture and use of chemicals from wood and other sources. Conclusive test results are presented for numerous reactor-gasifiers, of which two are considered the most promising for wood gasification: the Moore-Canada and the Union Carbide Purox units. Chemicals from wood waste can technically be generated but converting other substances to chemicals is usually more efficient; examples are found in the manufacture of synthetic natural gas (syngas) from coal rather than wood waste, and methanol from natural gas rather than coal or wood.

The complex route to methanol production is paved with multiple steps, costs, and acreage requirements (1 acre of storage area for each 1-day supply of wood waste). Market data on retail prices, production costs, profits, and investments are categorically higher for wood conversion to chemicals, sugars, and phenolics than for conversion of other substances. Presently, it is not economically feasible to derive chemicals from wood wastes. In the 1975 market, in fact, it was uneconomical to produce furfural from a single wood waste facility.

(95) *Report of the Forest Products Subcommittee to the Massachusetts For. Program Review Board.* May 1977.

This report contains the subcommittee's recommendations for utilizing the State's wood resource, attending to open space needs, industry support, environment, and energy. Massachusetts harvested 75 million board feet (MMBF) of its timber in 1975 and milled a total of 90 MMBF using imported wood as well. Yearly net surpluses of growth for low-quality timber in the State are sizable; 116 MMBF for hardwood and 92 MMBF for softwoods. Annual unused mill residues amount to 1.3 MMBF and wood from cleared lands reaches 17.2 million cubic feet.

The subcommittee found it less desirable to use wood for energy than for other purposes of higher value. The article claimed that economics do favor wood's use as both a home and industrial fuel at the 1977 prices of oil and mill residues. The subcommittee's report recommended that firewood operators and dealers have their firewood inventories exempted from personal property taxes. Such an exemption would encourage the proper seasoning of wood prior to sale. Laws and regulations affecting forest resource utilization are also discussed.

(97) Rose, Dietmar W. "Fuel Forests versus Strip Mining—Fuel Production Alternatives," *J. of For.* Vol. 73, no. 8, pp. 489-493. 1975.

The report's abstract states: "Recent discussions of the potential of wood for producing energy have not been specific enough to warrant the generally too optimistic or pessimistic outlook. Fuel production alternatives must be examined case by case and must include all relevant costs and benefits. Rapidly changing prices for many energy carriers necessitate a continuous re-evaluation of production alternatives. A proposal for a fuel forest and an analytical framework to compare energy alternatives is described."

More gross and/or net energy is obtainable from coal mining operations on a particular site in Iowa than from

intensive biomass cultivation on that same site; however, energy from the latter activity can be produced to compete with other fuels. As a supplemental energy source, wood could help solve some major power problems, while benefitting the environment. In Iowa's case, giving fuel plantations more than supplemental energy responsibility would be clearly impossible due to inadequate supplies of and competition for land.

+(*98*) Rothacher, Jack. "Regimes of Streamflow and Their Modification by Logging," *Forest Land Uses and Stream Environment Symposium Proceedings.* Ore. State Univ., Corvallis. Pp. 40-54. 1971.

Logging and burning old-growth Douglas-fir forests on an experimental watershed in the Pacific Northwest increased annual water yields by 18 inches or more. Treatments generally resulted in year-long increases in streamflow as well as substantial increases in minimum streamflow during dry summers. If sedimentation is kept at a minimum, such increases in streamflow patterns will likely benefit aquatic habitat.

(*99*) Saeman, Jerome and others. "Report of Task Force on Energy and Forest Resources," *J. of For.* Vol. 75, pp. 294-296. May 1977.

How much energy can the wood industry provide from residue? Estimates on the annual dry tons of unused residues do not agree (130 and 149 million tons, for example), but the figures do amount to over 2 quadrillion Btus of energy. The wood industry produces 1.1 Qs collectively of its own energy by using its residues and purchases a net 1.5 Qs annually. Hence, if the wood industry were to utilize its unused residues in place of its purchased fuels, it could supply all of its own fuel, while leaving at least 0.5 Q for extra industrial energy consumption. Many companies which have substituted wood for fossil fuels have received high rates of return from their conversion investments.

(*100*) Sarles, Raymond L. "The Use and Value of Wood and Bark Residues in the Northeast," *The Northern Logger.* Vol. 23, no. 2, pp. 22-23, 38-39. 1974.

Prices for nearly all forms of wood residue are given so that the potential additional income to mills can be incorporated into waste wood utilization and disposal plans. Low prices per ton of residue (such as $4 per ton of raw bark or green shavings) usually mean that the wood is untreated. However, by processing the residue for byproducts, the value can more than double: chipped and screened tons of slabs, edgings, and the like go for

$9 to $10 a ton, and average 500 pounds per cubic yard of chips. In 60-pound bags, dried or even just baled wood shavings bring the highest of all residue prices—$33.33 per ton in 1974. Residues, though, are predominantly sold by the cubic foot or cubic yard rather than by the ton. Processed bark can sell from $5 to $5.50 per cubic year (450 lbs.) and for still higher prices if bagged. Residues ranged between $4 for raw bark and $57.50 for bagged dry shavings per ton.

Not only can residues offer added income to manufacturers willing to sell them, but they can also serve as an inexpensive fuel. According to another report completed 5 years ago, annual savings in energy costs of plants fueled by residues reduced the amortization period on the conversion investment to 2 to 3.3 years. Today, it would seem to be even less.

(*101*) Shelton, J. W. *The Woodburner's Encyclopedia.* Waitsfield, Vt.: Vermont Crossroads Press, Inc. 1976.

This sourcebook discusses the theory, practice, and equipment of wood energy, and explains the nature of wood, environmental impacts of burning, and energy generation to fuelwood users. The energy content of wood ranges from 15 to over 30 million Btus per cord. The amount of energy in an oven dry pound of wood is about the same for almost all species. Fuel cost comparisons are graphically represented for oil, wood, gas, and electricity. One example shows that at 50 cents per gallon, fuel oil is slightly less economical than a cord of wood at $60.

Evaluations of burner hardware prove that unless closed, stoves and fireplaces can increase the amount of heat a home needs by providing open drafts that draw warmed air out of the house. Because of their large oxygen consumption, fireplaces have similar disadvantages: they suck cold outside air into the house to "feed" the fire, thereby keeping the indoor temperature lower than would other burner types.

(*103*) Simmons, Fred C. "Status of Research in Utilization of Small Hardwoods," *J. of FPRS.* Vol. 4, no. 6, pp. 384-387. 1954.

When this paper was written in 1954, there were great surpluses of hardwood everywhere in the country east of the Great Plains, though good, high-grade trees were not usually accessible or in surplus. Much of the reason for the overabundance of hardwoods was that the prices they commanded were out of reach to many markets, notably charcoal wood and fuelwood. The market for these latter two products thus became supported on mill

residues. The pulpwood market was expected to take the residue-using route also. New York fuelwood consumers used nearly 44 percent more hardwood mill residues (fine and coarse) than logged fuelwood (roundwood) in 1952 (213,000 cords vs. 148,000 cords). The largest factor affecting the cost of roundwood hardwood cords was the price of delivering the wood from the forests to the plants.

+(*107*) Snyder, Gordon G., Harold F. Haupt, and George H. Belt, Jr. *Clearcutting and Burning Slash Alter Quality of Stream in Northern Idaho.* USDA For. Serv. Res. Pap. INT-168. 1975.

Knowledge of the impact of timber harvesting on stream water quality is needed for different ecosystems. In the cedar-hemlock-grand fir ecosystem of the northern Rocky Mountains, changes in water quality caused by clearcutting and subsequent slash burning were evaluated. Significant nutrient increases occurred in streamflow through treated sites. Increases were small at downstream locations, except for one stream where downstream nutrient uptake increased as water moved laterally through nutrient enriched surface layers. Buffer strips are effective as physical barriers to direct contact with the nutrient source.

Edward Sprague, field representative, USDA For. Serv., Portsmouth, N.H., July 21, 1977, letter to Stephen G. Twombly on the supply of wood for fuel.

Fiber Removal Needed to Upgrade the Six-State New England Forest Area.

Item	Softwood	Hardwood
	1,000 cubic feet	
Mortality/year	116,768.0	78,412.0
Sound volume/year:		
Rough trees	67,168.6	58,225.5
Rotten trees	34,939.4	52,428.5
Topwood:		
New growth/year	240,292.8	207,740.0
Thinnings/year	106,060.0	172,985.0
Subtotal	565,228.8	569,791.0
Less roundwood harvest for all products	336,773.0	184,298.0
Total necessary removal	228,455.8	385,493.0

(*109*) Stuart, Craig. *Household Fuelwood Use and Procurement in Franklin County.* Turner Falls, Mass.: Franklin Com-

munity Action Corp. in cooperation with the Franklin County Planning Dept. 1978.

The residents of Franklin County, Mass., were surveyed to determine the extent of fuelwood use and the means of procuring wood in the county. The phone survey identified 48 percent of the county residents as wood burners who collectively consumed 38,000 cords during the winter of 1977-78 (a 23-percent increase in consumption over the 1976-77 winter). Forty-two percent of the residents rely on firewood as a major source of their heat; they consume more than 4 cords of fuelwood per year. Over half the fuelwood users cut all their own wood, but 38 percent of all the wood consumed was bought. Fifty-nine percent of the wood fuel consumers found it difficult to locate well-seasoned wood to buy; 66 percent of the respondents said they would have bought more wood if it was available and well seasoned. Interestingly, there was an overwhelming willingness (84 percent) to buy fuelwood in the spring or early summer if consumers could receive a $5 savings on the price of each cord of wood.

+(*110*) Swift, L. W., Jr. and J. B. Messer. "Forest Cuttings Raise Temperatures of Small Streams in the Southern Appalachians," *J. of Soil and Water Conserv.* Vol. 26, no. 3, pp. 111-116. 1971.

Cutting all trees and understory vegetation on small watershed in the southern Appalachians resulted in increasing maximum summer stream temperatures by as much as 12°F above the normal 66°F which may exceed the optimum for trout habitat. Where streambank vegetation was uncut or had regrown, maximum summer temperatures remained unchanged.

(*111*) Szego, George and Clinton C. Kemp. "Energy Forests and Fuel Plantations," *Chem. Tech.* Pp. 275-285. May 1973.

This paper examines the production of forests and other vegetation specifically for energy purposes on what are termed "fuel plantations." Energy from plant matter is more advantageous than fossil fuel energy because it is essentially sulphur-free, its residual ashes can be applied to the land, carbon dioxide levels are not upset, the energy can be supplied in proximity to its users, and the potential environmental consequences involved do not appear at all serious. These assets cannot be claimed for fossil or nuclear fuels.

Almost 350 square miles of pulpwood (softwood) forests can support a 1,000-ton per day kraft pulp mill, or could alternatively support a 400-MW electric plant fired with wood. Softwoods have an approximate air-

dried fuel value of 7,000 Btus per air-dried pound, whereas hardwoods usually generate 5,800 Btus. The calculated costs of wood fuel production are based on the yield of fuel per unit time (for example, on Btus per acre per year) and on the cost incurred per unit plantation area per unit time (such as dollars per acre per year).

(*112*) Tennessee Valley Authority. *Wood Residue for Energy: An Economic Analysis for Maryville College* (unpublished report). Maryville, Tenn. August 1977.

This report itemizes the annual fuel (oil and natural gas) costs incurred by Maryville College from 1972 through March 1977. The total energy consumption declined because of applied conservation measures from 48 billion Btus in 1972 down to their lowest at 30 billion Btus in 1975 (with a slight rise in 1976 to 35 billion caused by colder temperatures). Oil and natural gas heating costs (including fuel purchases) spiraled 111 percent from $70,000 in 1972 to $148,000 in 1976.

Converting to wood fuel was not a major problem for the college's existing systems. Based on a maximum requirement of 5,961 tons of residue wood fuel per year, net savings were expected to exceed $1 million over a 10-year period. A guaranteed 5-year wood supply from a neighboring wood-based industry was negotiated for $4 per ton, delivered but not unloaded for the first year, $5 for the second year, and an unfixed price not to exceed $7 for the last 3 years, plus contract renewal opportunities thereafter.

(*113*) Thompson, Wayne. "Chips from Residues Boost Wood Recovery by Mills," *W. Conserv. J.* Vol. 31, no. 3, pp. 24-26. 1974.

This article was written when it was still slightly cheaper to use oil and natural gas rather than wood for steam generation. It was determined that a 50-MW power plant would use 375,000 tons of residue wood per year, costing a minimum of 20 mills per kWh and even then assumed that fuel transportation would require subsidizing. Compared with hydropower at 2.5 mills per kWh, wood was barely in the running. A consulting engineer maintained that unless transportation costs for wood refuse could be written off as a logging expense and not recorded as an operational cost of power plants, wood energy generation projects would not be feasible.

Another alternative use for wood residues would be crude oil production at an expected yield of 1.1 to 1.2 barrels of crude oil per day per ton of mill residues. It is more economical to generate steam in lieu of crude oil

because 1 dry ton of wood makes enough steam to equal 2.2 barrels of oil. Processing plants might possibly be designed to turn out 3 to 3.5 barrels of oil per ton of refuse. This would make crude oil a more economical product than steam.

(*117*) U.S. Department of Agriculture. *For. Assistance Program in Cooperation with State For. Agencies.* For. Serv. GPO 901-177. June 1974.

This pamphlet describes 16 government programs which contribute technical and financial assistance for public and private forest land management. Primary management objectives include the control of pests, disease, forest fires, environmental deterioration, and flood and watershed protection. The encouragement of silvaculture through programs related to forest products utilization, planting and reforestation, conservation and development is a central feature of these programs. In all programs, various cost-sharing levels are established by State and Federal authorities to handle part of each program's expense. Three programs specifically offer free technical assistance to private landowners: the Rural Environmental Program, Assistance to States for Tree Planting and Reforestation Program, and the Forestry Incentives Program.

(*123*) Weed, Edgar M. *Vital Statistics—Vermont State Hospital Wood Chip Burning Project* (unpublished paper). Montpelier, Vt.: Division of State Buildings. September 1977.

The Vermont State Hospital's wood chip burning project was scheduled to commence December 15, 1977 and came on-line on January 1, 1978. Wood chips supply half of the fuel for the steam boiler (10,000 lbs. of steam, or 9.75 million Btus per hour maximum capacity). Five thousand tons of whole-tree chips (at $16 per ton) were bought at 40- to 50-percent moisture content. Forty-five tons of wood chips are fed into the burner per day and all performance results for wood fuel will be compared to the performance of no. 6 fuel oil, which supplies the second half of the boiler's fuel. A fuel cost comparison for numbers 2 and 6 fuel oil, wood, and coal is given for the cost of heating a square foot of office space, although the data is now outdated.

(*126*) Worley, David P. and Hoyt A. Wheeland. *An Economic Evaluation of Cull-Tree Removal in Mixed Hardwood Stands.* USDA For. Serv. Res. Note NE-82. 1968.

Over a 12-year span, the Kaskaskia Experimental Forest in Illinois was studied to determine value changes resulting from TSI methods, specifically cull removal.

Three of the six areas tested were harvested of their merchantable timber and cull trees, or the culls were killed and left standing. On the remaining three sites, only the merchantable sawtimber was taken and culls remained, untreated. Cutting was done on an improvement and group selection basis for both sets of areas with the intention of increasing the yields in medium and high quality sawlogs. Stands benefitted both physically and economically from cull removal and negative values resulted on those stands where culls were left alone. Cull killing or removing paid for itself in two out of three cases.

Over time, those sites with unmanaged culls can be expected to continually lose value because their relative volumes of cull will increase, subtracting that land from higher quality yields. Conversely, as TSI techniques create smaller and smaller volumes of cull trees, cull harvest volumes and therefore TSI costs on cull-treated areas will both decline. Sawtimber yields will also improve in volume and quality.

(*128*) Young, Harold E. "The Enormous Potential of the Forests: A Positive Rebuttal to Grantham and Ellis," *J. of For.* Vol. 73, no. 2, pp. 99-102. 1975.

This paper rebuts virtually one sentence proferred by Grantham and Ellis: "conversion of all collectible organic waste to energy would provide less than 2 percent of [the Nation's] requirements." The grounds for rebuttal are based on the implication in the statement that this potential energy is too negligible to be considered. The article maintains that efforts to increase American energy independence, including wood burning, are necessary. Also, the authors, under fire, base their conclusions not on the complete tree concept but rather on the merchantable bole concept, which is increasingly losing favor with foresters where biomass energy is involved. It is believed necessary to determine the biomass inventory of the forests on a dry weight basis for a better gauging of the growing stock supply. Armed with this data, wood as it relates to energy and other concepts can be more adequately assessed.

(*129*) Young, Harold E. "The Machines Are Coming, The Machines Are Coming." Presented at the "Economics and Harvesting of Thinnings" meeting, Edinburgh, Scotland. September 30-October 10, 1974.

As Young defines the complete tree concept, it is the "biological and technological investigation of the entire tree from the root tips to the leaf hairs inclusive," and involves shrubs, successional species, seedlings and

saplings of commercially used species. This concept redefines harvests to mean complete tree removal, with proper methods to maintain nutrient levels and prevent erosion. The public uproar over the environmental harm that increased harvesting could have on the forests may only be expressions of outrage against mechanization rather than a justified concern for the forest ecosystem.

Precommercial thinnings are now profitable and marketable (such as for pulp) due to new technologies. Thus the term precommercial is obsolete. The mobile Morbark chipharvester uses one operator, chips boles up to 20 inches in diameter, and turns out 120 tons of chips in 8 hours. The Koch Stump Remover (which severs lateral roots and removes the main taproot of southern pines) and the Palleri Stumpharvester (which removes stumps from peat bogs and swamps) are successful, although both have technical limitations. How well suited the machinery is for the logging site and the type of operation is what mainly determines its success. Therefore, biological and technological knowledge need to be more fully integrated.

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(*2*) Arola, Rodger A. "Logging Residue: Fuel, Fiber, or Both?" *ASAE Trans.* Vol. 18, no. 6, pp. 1,027-1,031. November/December 1975. (Pap. no. 74-1550, 1974).

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GLOSSARY

Airtight stove—A stove which is sufficiently airtight that its performance would be indistinguishable from a stove of the same overall design which was literally airtight. Generally, nonairtight stoves are less energy efficient and their level of heat output is less controllable than airtight stoves (*101*).

Allowable harvest—The volume of timber that would be cut on commercial timberland during a given period under specified management plans aimed at sustained production of timber products (*119*).

Annual forest growth—The growth on initial growing stock plus ingrowth from saplings, less the volume from growing stock removed due to death from natural causes and the volume of growing stock which becomes rough and rotten (*83*).

Annual timber removals—The volume of growing stock harvested and/or killed in logging operations, plus the volume of growing stock removed for cultural operations such as timber stand improvement, land clearing, or changes in land use (*83*).

Average annual net growth of growing stock—The change (resulting from natural causes) in volume of sound wood in sawtimber and poletimber trees during the period between surveys, divided by the length of the period. Components include the increment in net volume of trees present at the beginning of the period and surviving to its end, plus net volume of trees reaching poletimber size during the period, minus the net volume of trees that died and trees that became rough or rotten during the period (cull increment) (*61*).

Average annual mortality of growing stock—The net cubic foot volume removed from the growing stock because of death from natural causes during the period between surveys, divided by the length of the period between surveys (*61*).

Average annual growing stock removals—The net cubic foot volume of growing stock trees harvested and/or killed in logging, cultural operations such as timber stand improvement, land clearing, or changes in land use during the period between the surveys, converted to an annual basis (*61*).

Basal area—The area of the cross section of a tree at breast height; for a stand, the total basal area per unit of land area, usually per acre (*83*).

Biomass—The total mass or amount of plant material in an area. Includes that material between the tip of the roots to the

tips of the tops. Usually given in tons of dry (20-percent moisture) matter.

Bole—The trunk or stem of a tree (*83*).

Btu (British thermal unit)—A unit for measuring energy, equal to the amount of energy necessary to increase the temperature of 1 pound of water by 1 degree F. (*83*).

Coarse residue—Plant residue suitable for chipping, such as slabs, edgings, and veneer cores (*119*).

Commercial forest land—Forest land that is producing or capable of producing crops of industrial wood (more than 20 cubic feet per acre per year) and is not withdrawn from timber utilization. (Industrial wood: all roundwood products except fuelwood) (*61*).

Commercial species—Tree species that are present or prospectively suitable for industrial wood products. Excludes species of typically small size, poor form, or inferior quality, such as hawthorn and sumac (*61*).

Complete tree concept—The "biological and technology investigation of the entire tree from the root tips to the leaf hairs inclusive" (*60*, p. 4). The philosophy behind application of this concept is to "use as much of the standing vegetation as possible to minimize waste consonant with the principles of forest ecology." "Whole-tree, full tree, and total tree" are terms that usually do not involve below-surface components of trees, and therefore, are different from the term "complete tree" (*60*).

Cord—A common measure of firewood and pulpwood, equal to the amount of wood in a carefully stacked (parallel) pile of wood which is 4 feet high, 8 feet wide, and 4 feet deep. The amount of solid wood in this 128 cubic foot pile is usually estimated to be between 80 and 90 cubic feet (*101*)

Creosote—Chimney deposits originating as condensed organic vapors or condensed tar fog. Creosote is often initially liquid, but may dry and/or pyrolyze to a solid or flaky form (*101*).

Cull increment—The net volume of growing stock trees on the initial inventory that had become rough or rotten trees by the time of the second inventory (*61*).

Cull material—A log or tree which has a large percentage of defects so as to make it unmerchantable (*83*).

Diameter at breast height (dbh)—The diameter outside bark of a standing tree measured at 4.5 feet above the ground (*83*).

Efficiency or energy efficiency—As applied to a wood stove, the fraction (or percentage) of the chemical energy in the wood which is converted to useful heat by the stove, including the heat from an average amount of exposed stovepipe (about 6 feet) (*101*).

Forest land—Land that is at least 16.7 percent stocked (contains at least 7.5 square feet of basal area) by forest trees of any size, or that formerly had such tree cover and is not

currently developed for nonforest use. (Forest trees are woody plants that have a well-developed stem and usually are more than 12 feet in height at maturity.) The minimum area for classification of forest land is 1 acre (*61*).

Green wood—Undried, freshly cut wood from a live tree (*101*).

Growing stock trees—Live trees of commercial species that are classified as sawtimber, poletimber, saplings, and seedlings; that is, all live trees of commercial species except rough and rotten trees. (See the definitions in (*61*) under "Class of timber.")

Growing stock volume—Net volume, in cubic feet, of live growing stock trees that are 5 inches dbh and over, from a 1-foot stump to a minimum 4-inch top diameter outside bark of the central stem, or to the point where the central stem breaks into limbs. New volume equals gross volume less deduction for rot and/or sweep and crook (*61*).

Hardwoods—Dicotyledonous trees that are usually broadleaved and deciduous (*61*).

Heartwood—The wood in the center of a tree extending out to the sapwood. The heartwood no longer participates in the tree's life processes. It is usually darker in color and more resistant to decay. Very young trees have no heartwood (*101*).

High heat value—The chemical energy per unit mass of wood. The high heat value represents the amount of chemical energy released if one mass unit of wood is completely burned. Some of the energy will be in the form of latent heat (a form of potential energy) unless the water vapor in the combustion products condenses (*101*).

Hogged wood fuel or hogged fuel—The particles produced by a mechanical shredder. May also include sawdust, wood shavings, and ground bark (*83*).

Ingrowth—The number or net volume of trees that grow large enough during a specified year to qualify as samplings, poletimber, or sawtimber (*119*).

Latent heat—The potential energy in water vapor which is converted into (sensible) heat when the vapor condenses. A pound of water vapor at room temperature has about 1,050 Btus of latent heat (*101*).

Logging residues—The unused growing stock volume of trees cut for products and the total stock volume of trees destroyed in the course of logging but not removed for products (*83*).

Low heat value—The chemical energy per unit mass of wood, minus the latent heat in the water vapor which would result from the complete combustion of wood. The low heat value is the amount of (sensible) heat produced when a unit mass of wood is burned completely and no resulting water vapor condenses (*101*).

Mill residues—The materials that remain after the manufacture of wood products, such as sawdust, shavings, chips, and bark (*83*).

Multiple use management—The management of land resources aimed at achieving optimum yields of products and services from a given area without impairing the productive capacity of the site (*119*).

Noncommercial forest land—Forest land that is incapable of yielding timber crops because of adverse site conditions (unproductive forest land), and productive forest land that is withdrawn from commercial timber use (productive-reserved forest land (*61*).

Open or openable stove—A stove designed to be operable with open doors, exposing the fire to direct view. An example is the Franklin stove (*101*).

Ovendry wood—Wood which has been dried to constant weight at about 215 degrees F. and low humidity. By definition, ovendry wood has zero moisture content (*101*).

Plant byproducts—Wood products such as slabs, edgings, and veneer cores that are obtained incidental to the production of timber products and are utilized in the manufacture of other timber products. (Bark is not included) (*61*).

Plant material conversion: Four techniques for converting plant material into liquid and gaseous fuels (*101*)—

Chemical reduction—Involves heating under pressure in the presence of water, carbon monoxide and catalyst. The principal product is an oil with a heating content of about 120,000 Btus per gallon (heating oil has an energy content of about 140,000 Btus per gallon).

Enzymatic reduction—Not yet as developed as the other three processes. It would involve the use of enzymes (substances produced in living cells) to assist simple chemical transformations of wood to simpler substances.

Fermentation—In a moist, warm, and anaerobic environment, some organic materials may be fermented to a gaseous fuel (mostly methane) and carbon dioxide. Sixty to 80 percent of the original stored energy is converted in this process. After removing the carbon dioxide and small amounts of sulfur-containing compounds, the gas is essentially identical to natural gas, and thus is readily usable in existing gas-burning furnaces and appliances.

Pyrolysis—Involves heating the organic matter in the absence of oxygen. This has long been done with wood to make turpentine, methanol, acetic acid, creosote and charcoal. In general, liquids, gases and solids are all formed in this process and all can be used as fuels.

Plant residues—Wood material produced incidental to the production of timber products but not utilized (*61*).

Productive reserved forest land—Forest land that is sufficiently

productive to qualify as commercial forest land, but is withdrawn from timber utilization through statute, administrative designation, or exclusive use for Christmas tree production (*61*).

Pyroligneous acid—The acidic brown aqueous liquid obtained by condensing the gaseous products of pyrolysis of wood. Pyroligneous acid is the same as creosote in its wettest form (*101*).

Pyrolysis—The chemical destruction of wood by the action of heat alone, in the absence of oxygen and hence without burning. The products of pyrolysis are gases, tar fog, and charcoal (*101*).

Rotten trees—Live trees of commercial species that do not contain at least one 12-foot sawlog or two noncontiguous sawlogs, each 8 feet or longer, now or prospectively, and do not meet regional specifications for freedom from defect primarily because of rot; that is, when more than 50 percent of the cull volume in a tree is rotten (*61*).

Rough trees—(a) The same as above, except that rough trees do not meet regional specifications for freedom from defect primarily because of roughness or poor form, and (b) all live trees that are of noncommercial species (*61*).

Roundwood—Merchantable bole (see "bole") (*83*).

Sapwood—The wood extending from the heartwood out to the bark in a tree. Sapwood participates in transporting sap up and down a tree. Sapwood usually is lighter in color than heartwood and is more suspectible to decay (*101*).

Seasoned wood—Wood which has lost a significant amount of its original (green) moisture. The term has no more specific (and universally accepted) meaning (*101*).

Sensible heat—Energy in the form of random motions of molecules, atoms, and electrons. Sensible heat is the form of energy that is transferred from a warm object to a cooler object when they are in direct physical contact. Sensible heat can be sensed or felt directly by human skin. Infrared radiation (sometimes called radiant heat) is a completely different energy form which is transformed into sensible heat when it is absorbed by a surface such as skin. Latent heat is a form of potential heat which also cannot be sensed by humans, but can be converted into sensible heat (*101*).

Softwood—Coniferous trees that are usually evergreen, having needles or scale-like leaves (*61*).

Stocking—The degree of occupancy of land by trees, measured in terms of basal area of trees in a stand compared to the basal area of trees required to fully utilize the growth potential of the land (*83*).

Stumpage—The money paid to a landowner for the standing trees of his land; the term is sometimes incorrectly used to mean the standing trees (*83*).

Sustained yield—The rate at which wood can be harvested from an area forever, without decreasing the area's productivity. Sustained yield harvesting involves taking wood at a rate no larger than the rate at which new wood is growing (*101*).

Timber stand—A growth of trees on a minimum of 1 acre of forest land that is at least 16.7 percent stocked by forest trees of any size (*61*).

Timber stand improvement—Measures such as thinning, release cutting, girdlings, weeding, or poisoning of unwanted trees aimed at improving growing conditions (*119*).

Timber removals—The growing stock volume of trees removed from the inventory for roundwood products, plus logging residues and other removals (*61*).

Unproductive forest land—Forest land that is incapable of producing 20 cubic feet per acre per year of industrial wood under natural conditions, because of adverse site conditions (*61*).

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